# ELEMENTARY PRINCIPLES

OF

# CARPENTRY;

## A TREATISE

ON THE PRESSURE AND EQUILIBRIUM OF BEAMS AND TIMBER FRAMES; THE RESISTANCE OF TIMBER; AND THE CONSTRUCTION OF FLOORS, ROOFS, CENTRES, BRIDGES, &c.

*WITH PRACTICAL RULES AND EXAMPLES.*

TO WHICH IS ADDED,

AN ESSAY ON THE NATURE AND PROPERTIES OF TIMBER,

INCLUDING THE METHODS OF SEASONING, AND THE CAUSES AND PREVENTION OF DECAY, WITH DESCRIPTIONS OF THE KINDS OF WOOD USED IN BUILDING.

ALSO,

NUMEROUS TABLES

OF THE SCANTLINGS OF TIMBER FOR DIFFERENT PURPOSES, THE SPECIFIC GRAVITIES OF MATERIALS, &c.

*ILLUSTRATED BY TWENTY-TWO ENGRAVINGS.*

BY THOMAS TREDGOLD.

——— While we give ourselves infinite trouble to pursue investigations relating to the motions and masses of bodies which move at immeasurable distances from our planet, we have never thought of determining the forces necessary to prevent the roofs of our houses from falling on our heads. EDIN. REV. vol. vi. p. 386.

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TO

# WILLIAM ATKINSON, ESQ.

ARCHITECT TO THE ORDNANCE DEPARTMENT,

M. G. S. F. H. S. &c.

THIS WORK,

ON THE PRINCIPLES OF CONSTRUCTION IN ARCHITECTURE,

IS INSCRIBED BY

THE AUTHOR.

# PREFACE.

IN the course of the last century several treatises on Carpentry have appeared; but in none of them is to be found any thing on the mechanical principles of the art, except it be a few rules for calculating the strength of timber; and these are founded upon erroneous views of the subject, and therefore are not to be relied upon. The greater part of the works on Carpentry are confined almost wholly to what is termed "finding the lines;" a branch of science to which the celebrated Monge gave the name of Descriptive Geometry: and in the works of Mr. P. Nicholson this part of Carpentry has been so ably handled, that little more seems to be required on the subject.

But the knowledge of practical and descriptive geometry is not the only part of science that a carpenter ought to acquire; for when it is considered that the art of Carpentry is directed chiefly to the support of weight or pressure, it will be obvious that a considerable knowledge of the principles of mechanics is required to practise it with success. And it is not to carpenters alone that the study of the mechanical principles of Carpentry should be confined; for, in the modern practice of building, it forms one of the most important departments of the science of construction; and a knowledge of construction is so essential to the art of design, in Architecture, that it is difficult to believe how much it has been neglected, and how little it is esteemed by the students of that profession.

It would, however, be easy to show, that it is as necessary that an architect should understand construction, as it is that a painter, or a sculptor, should understand anatomy: in fact, construction is the anatomy of Architecture, it is the very base upon which the art of design must be founded, and on the

nature of the base must depend the excellence of the superstructure. So much have the principles of construction been neglected by many architects, that all works which require any considerable degree of skill in construction are now given to men of a new profession—to Civil Engineers. This division of the art might be an advantage, if the objects which require such skill were such as have no pretensions to visible beauty; but where beauty and solidity are to be combined, the study of the higher branch of Architecture, which consists in the production of visible beauty, must, necessarily, be joined with the study of construction.

As the mechanical principles of Carpentry have never been published in a separate form, I have attempted, in the following pages, to supply that defect; but, sensible of the extensive acquirements that are necessary to do justice to such a work, I should not have undertaken the task, had I had a hope of seeing it executed by an abler hand. It is much to be regretted, that works of this kind, like elementary works in science, though they require a considerable share of ability to execute them well, yet men of superior talent almost always neglect them in favour of more distinguished pursuits. But though I feel much diffidence in submitting the result of my labours to the public, I also am encouraged by the hope that they will be useful; and that if these labours have not been directed by the profound views of superior science, nor elucidated by the elegant and perspicuous language of a scholar, at least they have arisen out of a sincere love of knowledge, and have been guided by a zealous desire to extend and improve the art of building.

In the present state of society it is most desirable that stability and economy should characterize the different species of construction. A just economy of materials should be one of the first objects of the builder's attention, and this desirable object is to be obtained only by judicious combinations of the materials to be used; but unless the effect of pressure, and the resisting powers of the different materials be understood, how are such combinations to be designed? It is true that there are men, who, without education, have done works which are regarded with astonishment, even by men of science; such, for instance, was Brindley, or Grubenmann. But were these men ignorant of mechanics? or had they by their own mental application acquired

a knowledge of some of its most useful principles? The latter is by far the most probable conjecture.

It is, however, wholly unnecessary to advance reasons for adopting correct principles in preference to being guided by opinion, as opinions are often hastily formed upon confined or imperfect views of the real nature of the subject; and we can seldom, if ever, refer with any degree of certainty to the grounds on which they were founded; but a maxim drawn from science can always be examined, and traced to its origin.

But science remains a dead letter unless it be applied "to the business and affairs of men;" on the contrary, when it is applied to the useful arts, it extends the views of the artist, substitutes certainty for uncertainty, security for insecurity; it informs him how to raise the greatest works with confidence, and how to produce stability with economy, or, in its own language, how to obtain a maximum of strength with a minimum of materials.

There is perhaps no class of the mechanical arts so directly capable of receiving improvement from the researches of men of science as those connected with building; neither is there any that have received a greater share of their attention: but these researches have not benefited practical men in proportion to the extent to which they have been made, as they are either given in works that are inaccessible to the bulk of men of business, or so completely scientific, as to be almost useless to any but men of science themselves. It has been my object to make these researches the ground-work of a practical treatise.

But while I most earnestly recommend the study of the principles of construction, I must as earnestly protest against its abuse. It is necessary that an architect should understand geometry and mechanics, but dangerous for him to make either of them a favourite study; lest, like Father Guarini, (a Tuscan architect,) "he trifles with his knowledge," and employs himself "in inventing grotesque vaultings, and honeycombed cupolas, which have neither solidity nor beauty." It should be the architect's care to avoid every thing of the kind, and to aim at that simplicity of design which is most easy in the execution, and forms the most economical and the most durable structures. In this consists the true excellence of the art of construction; but I am aware that this kind of excellence seldom secures praise. Men are

better pleased with apparent artifice, or with a hardiness of design which nothing but the most profound ignorance of the art would allow any one to venture upon.

When science smooths the way, and renders it easy to project and to execute any design within the limits that will secure firmness and durability, wonders disappear, and the greatest works are carried on with confidence, and become little different from the common course of business.

The Elementary Principles of Carpentry being a title which includes all that is essential to the art, it therefore embraces a wider range than I have attempted to fill; and to avoid promising in a title more than is performed in the work, I have omitted the definite article, and made it "ELEMENTARY PRINCIPLES OF CARPENTRY*."

I have divided such parts of the elementary principles as form the subject of my work into ten sections; on these sections I have a few remarks to offer, for which this will be the fittest place.

The first section is devoted to explaining the nature and laws of pressure, with the application of these principles or laws to designing framing. In this section the review of the methods of spanning a wide opening, which is given in sect. VIII. art. 258—265, plate XVIII. ought to have been placed, as the principles are general, and apply to roofs, centres, &c. as well as to bridges, requiring only some slight modifications to fit them for each of these cases. Its proper place would therefore have been to follow art. 66 in sect. I. This defect was not noticed till it was too late to alter it.

In the first section I have attempted to supply only what appeared to be actually useful in Carpentry, the subject might have been treated at greater length, but a good treatise on mechanics will answer a better purpose to the student; as jointly they would be more complete than either would be separately. A system of mechanics is necessary to give the student an entire and comprehensive view of the science, as its several parts have a mutual influence toward the explanation and proof of each other; "and that man

* Lord Kames made a like limitation to his "Elements of Criticism," which of course suggested this.

is never fit to judge of particular subjects relating to any science who has never taken a survey of the whole."

The second section treats of the resistance of timber; and in the introductory remarks to that section I have endeavoured to point out in what it consists; from whence it will appear, that the rules for the resistance to fracture do not apply to the general purposes of building, and therefore tables of scantlings calculated according to such rules do not agree with those required in practice.

The second section contains the results of many new experiments, both on the stiffness and strength of timber. I have preserved specimens of the pieces tried; and, on account of the advantage I have reaped from making such a collection, I should be glad to find that the same practice is adopted by others. I have also been favoured with an account of several experiments made by Mr. R. Ebbels, together with specimens of the pieces tried. His selection of pieces for trial has been made with much judgment.

The third section is on the construction of floors; the fourth on roofs; the fifth on domes; and the sixth on partitions: these are the parts which demand the greatest part of the carpenter's attention in house-building; and in each of these sections I have endeavoured to show the most advantageous methods of construction, illustrated by examples.

The seventh section is on centres for bridges; a subject of much importance, in which some better principles of construction are shown than those hitherto published.

The eighth section is on wooden bridges, and it may appear to be extended to a greater length in proportion to its usefulness than was necessary; and yet, when it is considered that there are many situations where bridges are wanted, and where bridges of timber might be constructed at a small expense, and consequently without going beyond the funds that could be appropriated to such a purpose, a few pages on the subject will not appear to be altogether out of place: as I think it may be shown, that the first cost and subsequent repairs of a wooden bridge would be so small a burden upon the community in comparison with the expense of a stone, or an iron bridge, that the benefit of these useful structures might be extended to situations where at present it is unknown.

In order to prevent repetition, the construction of joints and straps is the subject of the ninth section; treating of them together gives an opportunity of comparing the different species of joints, and, therefore, of unfolding the principles of construction in a more distinct and effectual manner.

In the tenth section the nature and properties of timber are considered. In this department of my work I have endeavoured to exhibit a brief but comprehensive view of the most useful facts and observations that have been made on this important subject.

Classing the woods may appear to be a refinement not required in a work on Carpentry, but it is hoped that the following reasons for adding it will be thought satisfactory. In old specimens, there are some woods so nearly alike that they are often mistaken by common observers; now as it is desirable to know that kind which is most durable, it must be an advantage to have some character by which different kinds can be distinguished. For under the impression that chesnut was much employed by our ancestors, and that it is the durable kind of wood found in old buildings, the growth of it has been lately much encouraged. But I have examined many specimens of old wood that have been shown to me as chesnut, and without an exception they have proved to be of oak. Perhaps a closer investigation may show that the growth of chesnut has been encouraged on very superficial inquiries respecting its nature. The character which distinguishes oak from chesnut, is the same as that which distinguishes my two classes of woods; and the divisions are also founded on such distinctions as will convey useful information.

The numerous tables at the end of the work will not form the least useful part of it. The tables of scantlings were first calculated for my own use some years ago, and the arrangement is that which I found most convenient. They are the first that have been published of the kind, where the calculations have been made on the principles of the resistance to flexure.

As tables are limited to particular purposes, and calculation is an irksome labour to those who are not accustomed to it, I shall notice some of the means that may be used to lessen the labour. In the first place, the calculations may be much shortened by using a table of the powers and roots of numbers. Such a table may be found in Mr. Barlow's Mathematical Tables,

a work which contains many other very useful ones. Less extensive tables of powers and roots are given in Dr. C. Hutton's Course of Mathematics, vol. i.; in the first volume of the Mathematical Tracts of the same author; in Buchanan's Essay on the Shafts of Mills; and there is a French set of Tables des Quarrés et des Cubes, &c. by Séguin.

Tables of logarithms may be used with much advantage for lessening the trouble of calculation; and it was my intention to have given the rules for the logarithmic mode of computation only; but the application is so easy to any one so far conversant with logarithms as to be able to use the tables, that to give them according to the common method is perhaps preferable.

The sliding-rule may also be employed as a means of reducing the labour. It is much to be regretted that this useful instrument is not much oftener employed in arithmetical operations. The improved, or rather the new sliding-rule of Dr. Roget (see Philosophical Transactions for 1815) is better adapted for the operations in many of the rules of this work than the common one. But with the common one, and a table of powers and roots, many of the operations may be performed by inspection only.

Convenience of reference is so desirable in a work of this kind, that I have employed every means that appeared likely to obtain it. Besides the division of the work into sections, it is also further divided into short articles, numbered in a continued series from the beginning to the end. The figures on the plates are also numbered in a continued series; and each figure has a reference to the article where it is described, which will often save much trouble in finding the description. The table of contents refers to both the page and the article; the index to the page only, as custom has rendered it more easy to turn to a subject by means of the number of the page than by means of that of the article.

When any other part in this work is referred to, the reference is given in the text between parentheses; but in referring to other works, the reference is given at the foot of the page. Some of my readers may think that so many references to different writers might have been dispensed with; but if in any of them it rouses a spirit of inquiry, one good effect that I had in view will be obtained. Besides, justice demands that the builder should know to whom he is indebted for investigating the principles of his art. It

cannot be altogether uninteresting to any one to know, that Galileo, Mariotte, Leibnitz, Euler, Bernoulli, Lagrange, Emerson, Girard, Hutton, Robison, Young, and many other celebrated men, have directed their talents to the improvement of the principles of building: and in collecting from the rich store of materials that are scattered through their works, surely the agreeable duty of pointing out the sources will not be denied me; nor yet will reference be objected to when my own essays are supported by showing their agreement with higher authorities. If I have not always noticed where I have trodden in the steps of others, it was more from the want of the means than from the want of the will. My claims to novelty are few, as after a little research I have often had the mortification to find the ground already occupied which once appeared to be my own.

The tables of specific gravities, at the end of the volume, were collected, and the plates were drawn, by my brother, R. Tredgold; the merits or demerits of the rest of the work are my own. In executing it I have laboured under many disadvantages; it has been written in the short intervals between the hours of business, with very limited means of consulting the works of others, and without the advantage of any other education than that of which my own industry has made me master. On these grounds then I claim the indulgence of the reader; and I hope, that after an impartial review of the whole, he will find more to approve than to condemn.

London,
April 20, 1820.

# CONTENTS.


| | Article | Page |
|---|---|---|
| INTRODUCTION | 1—3 | 1 |

SECT. I.—OF THE EQUILIBRIUM AND PRESSURE OF BEAMS.

| | | |
|---|---|---|
| Composition and Resolution of Forces | 7—14 | 3 |
| Effect of Position | 15 | 5 |
| To measure the Strains in a Framed Truss | 16, 17 | 6 |
| Of Framed Levers | 18 | 6 |
| Effect of Position further considered | 19—21 | 7 |
| To distinguish Ties from Struts | 22, 23 | 9 |
| To find the Resultant of a System of Forces | 24—29 | 10 |
| Of the Centre of Gravity | 30—34 | 12 |
| Of the Pressure of Inclined Beams | 35—43 | 13 |
| Of the Strain upon Beams laid horizontally | 44—46 | 16 |
| Of the Equilibrium of an Assemblage of Beams | 47 | 17 |
| Of the Points of Fracture in a System of Framing | 48—55 | 17 |
| To determine the Curve of Equilibrium | 56—61 | 19 |
| ——— for a Cupola or Dome | 62—66 | 22 |
| General Observations on designing Framing | 67 | 24 |

SECT. II.—OF THE RESISTANCE OF TIMBER.

| | | |
|---|---|---|
| Introductory Remarks | 68 | 25 |
| Definitions and general Principles | 69—71 | 26 |

*On the Resistance to Tension.*

| | | |
|---|---|---|
| Stiffness of Beams to resist a Strain in the direction of their length | 72—74 | 27 |
| Table I. of constant Numbers for calculating the Resistance to Tension | 73 | 28 |
| Strength of Beams to resist a Strain in the direction of their length | 75—77 | 28 |
| Table II. Cohesive Force of a square Inch of different Woods | 76 | 29 |
| —— III. ——— Woods strained in a direction perpendicular to the Fibres | 77 | 29 |
| —— IV. ——— Iron | 78 | 30 |

*On the Resistance to Cross Strains.*


| | ARTICLE | PAGE |
|---|---|---|
| Of the Stiffness of Beams to resist Cross Strains | 79 | 30 |
| ——— supported at both ends | 80—84 | 31 |
| Duhamel's Experiments on Oak | 85 | 33 |
| Table V. Experiments on the Stiffness of Oak | 86 | 34 |
| —— VI. ——— Fir | 87 | 35 |
| —— VII. ——— various Woods | 88 | 36 |
| Practical Rules for the Stiffness of Beams | 90—94 | 37 |
| When a Beam is fixed at both ends | 95 | 39 |
| Of the Stiffness of a Cylinder supported at both ends | 96, 97 | 39 |
| On the Stiffness of Beams to resist a Weight diffused over their length | 98, 99 | 40 |
| ——— supported at one end | 100—102 | 41 |
| Table VIII. Experiments on the Stiffness of Beams supported at one end | 101 | 41 |
| On the Stiffness of Beams fixed at one end, when the Weight is uniformly diffused | 103 | 42 |
| On the Strength of Beams to resist Cross Strains | 104—116 | 42 |
| ——— supported at both ends | 105—109 | 42 |
| Table IX. Experiments on the Strength of Beams | 108 | 44 |
| Rules for calculating the Strength of Beams supported at both ends | 110—112 | 45 |
| Strength of Beams supported at one end | 113 | 46 |
| Table X. Experiments on the Strength of Beams | 114 | 46 |
| On the Resistance to Detrusion, or Crushing across close to a fixed Point | 115, 116 | 46 |


*On the Resistance to Compression.*


| | ARTICLE | PAGE |
|---|---|---|
| On the Strength of Columns, Posts, &c. to resist Flexure | 118—122 | 48 |
| Table XI. Experiments on the Resistance to Compression, by Lamandé | 123 | 51 |
| —— XII. ——— Girard | 124 | 52 |
| —— XIII. Data for calculating the Strength of Columns | 124 | 54 |
| Practical Rules for the Strength of Columns, Posts, &c. | 125—127 | 55 |
| ——— Curved Ribs | 128 | 56 |
| On the Resistance to Crushing, with Experiments | 130, 131 | 58 |
| ——— Compression at the Joints of Framing | 132 | 60 |


SECT. III.—OF THE CONSTRUCTION OF FLOORS.


| | ARTICLE | PAGE |
|---|---|---|
| Kinds of Naked Flooring described | 133—136 | 61 |
| Of Single Joisted Floors | 137 | 62 |
| Of Framed Floors | 138—155 | 63 |
| Girders | 138—148 | 63 |
| Binding Joists | 149—152 | 67 |

| | Article | Page |
|---|---|---|
| Of Framed Floors—Bridging Joists | 153 | 68 |
| Ceiling Joists | 154, 155 | 68 |
| General Observations respecting Floors | 156—158 | 69 |
| Of Floors constructed with short Timbers, and Description of a curious Floor at Amsterdam | 159, 160 | 70 |

SECT. IV.—OF THE CONSTRUCTION OF ROOFS.

| | | |
|---|---|---|
| Introductory Remarks | 161 | 72 |
| On the Pitch of Roofs | 162, 163 | 73 |
| On the Forms of Roofs for different Spans | 164—175 | 74 |

*On Proportioning the Parts of Roofs.*

| | | |
|---|---|---|
| Of King Posts | 177 | 79 |
| Of Queen Posts and Suspending Pieces | 178—180 | 80 |
| Of Tie Beams | 181—183 | 81 |
| Of Principal Rafters | 184—186 | 82 |
| Of Straining Beams | 187 | 83 |
| Of Struts and Braces | 188, 189 | 84 |
| Of Purlins | 190 | 84 |
| Of Common Rafters | 191 | 85 |

*Description of Roofs that have been executed.*

| | | |
|---|---|---|
| Roof of the Basilica of St. Paul, at Rome | 192 | 85 |
| ——— Theatre d'Argentina, at Rome | 193 | 86 |
| ——— Riding House at Moscow | 194 | 87 |

SECT. V.—OF THE CONSTRUCTION OF DOMES.

| | | |
|---|---|---|
| Definitions and introductory Remarks | 195, 196 | 88 |
| On the Construction of Domes that admit of Horizontal Cross Ties | 197 | 88 |
| ——— without Horizontal Cross Ties | 198—200 | 89 |

SECT. VI.—OF THE CONSTRUCTION OF PARTITIONS.

| | | |
|---|---|---|
| Introductory Remarks, Scantlings for Partitions for common purposes, and Principles of Construction | 201—206 | 91 |

SECT. VII.—OF THE CONSTRUCTION OF CENTRES FOR BRIDGES.

| | | |
|---|---|---|
| Definition and introductory Remarks | 207, 208 | 94 |
| Pressure of the Arch-stones upon Centres | 209—214 | 95 |

| | Article | Page |
|---|---|---|
| On Designing Centres | 215—220 | 98 |
| On the Construction of Centres | 221 | 101 |
| On Removing Centres | 222 | 101 |
| On Computing the Strength of Centres | 223—225 | 102 |


### Sect. VIII.—Of Wooden Bridges.


| | Article | Page |
|---|---|---|
| Notices of Ancient Bridges, of those of the Middle Ages, of the Bridges of Palladio, and of the celebrated Bridge over Portsmouth River in America | 226—233 | 106 |
| Schaffhausen Bridge | 234 | 108 |
| Freysingen Bridge | 235 | 109 |
| Bridge of Bamberg | 236 | 111 |
| Table of the Dimensions of the Bridges constructed with Curved Ribs by Mr. Wiebeking | 238 | 112 |
| Table of the Spans of some of the most celebrated Wooden Bridges in Europe | 239 | 113 |
| Of Designing Wooden Bridges | 240 | 113 |
| Of the Width of Bridges | 241 | 114 |
| Of the Width of Water-way that ought to be left for the River | 242—246 | 115 |
| Of the Span of the Arches | 247—249 | 118 |
| Of the Construction of Abutments | 250 | 122 |
| ——— Piers | 251—257 | 123 |
| ——— Arches, or Timber Frames, of Wooden Bridges | 258—269 | 125 |
| Table of the least Rise for different Spans, with Mr. Wiebeking's Rule for calculating the Settlement | 270—271 | 132 |
| On forming the Road-way and Parapets | 272 | 132 |
| On determining the Scantlings of the Timbers for Bridges | 273—277 | 133 |


### Sect. IX.—Of Scarfing, Joints, and Straps.


| | Article | Page |
|---|---|---|
| Introductory Remarks | 278, 279 | 136 |
| I. Of Lengthening Pieces of Timber to resist Tension | 280—290 | 137 |
| II. Of Lengthening Beams to resist Cross Strains | 291—293 | 139 |
| Of Building Beams | 294 | 140 |
| III. Of Lengthening Beams to resist Compression | 295 | 141 |
| IV. Of the Joints of Framing | 296—306 | 141 |
| V. Of Joints for Ties and Braces | 307, 308 | 146 |
| Of Straps | 309—311 | 146 |

## Sect. X.—On the Nature and Properties of Timber.


| | Article | Page |
|---|---|---|
| Of the Structure of Wood, the Motion and Nature of Sap in Trees, and their Age | 312—317 | 149 |
| Of Felling Timber | 318—320 | 152 |
| Of Seasoning Timber | 321—326 | 155 |
| Water Seasoning | 322 | 156 |
| Steaming and Boiling Timber | 323 | 157 |
| Smoke-drying, Scorching, and Charring Timber | 324 | 158 |
| Tables of the Weight of Timber in different States | 325 | 159 |
| Laws of Seasoning | 326 | 161 |
| Of the Decay of Timber | 327—337 | 164 |
| Effect of continued Dryness | 327 | 164 |
| ——— Wetness | 328 | 164 |
| ——— alternate Dryness and Moisture | 329 | 165 |
| ——— continued Moisture with Heat | 330—337 | 165 |
| Of the Prevention of Decay | 338—364 | 171 |
| Repairs of Buildings affected with the Rot | 348—353 | 174 |
| Preserving Wood exposed to the Weather | 354 | 175 |
| Prevention of the Ravages of Worms and Insects | 355—358 | 176 |
| Durability of Timber in different States | 359—365 | 178 |
| Table of the Quantity of Charcoal in different Woods | 364 | 182 |


## Of the Structure and Classification of Woods.


| | Article | Page |
|---|---|---|
| Table exhibiting the Arrangement of the Species of Woods | 367 | 185 |


*Description of Woods.*


| | Article | Page |
|---|---|---|
| Class I.—Division I. | | 187 |
| Description of Oak | 376 | 188 |
| Division II. | | 193 |
| 1. Description of Beech | 378 | 193 |
| 2. ——— Alder | 379 | 195 |
| 3. ——— Plane Tree | 380 | 196 |
| 4. ——— Sycamore | 381 | 197 |
| Class II.—Division I. | | 197 |
| 1. Description of Chesnut | 384 | 198 |
| 2. ——— Ash | 385 | 200 |
| 3. ——— Elm | 386 | 201 |
| 4. ——— Common Acacia | 387 | 203 |
| Division II. | | 204 |
| 1. Description of Mahogany | 389 | 204 |
| 2. ——— Walnut | 390 | 205 |
| 3. ——— Teak | 391 | 206 |
| 4. ——— Poplar | 392 | 207 |

| | | Article | Page |
|---|---|---|---|
| Class II.—Division III. | | | 208 |
| | 1. Description of Cedar of Libanus | 394 | 208 |
| | 2. ——— Red or Yellow Fir | 395 | 209 |
| | 3. ——— White Fir or Deal | 396 | 212 |
| | 4. ——— American Pines; 5. Pitch Pine; 6. Silver Fir; and, 7. Pinaster | 397—401 | 214 |
| | 8. ——— Larch | 402 | 215 |
| | 9. ——— Cedar | 403 | 217 |


Tables of Scantlings, Specific Gravities, &c.


| | | Page |
|---|---|---|
| Table I. | Of Scantlings for Girders | 219 |
| —— II. | ——— Binding Joists | 220 |
| —— III. | ——— Single and Bridging Joists | 221 |
| —— IV. | ——— Ceiling Joists | 222 |
| —— V. | ——— Roofs from 20 to 30 feet span | 223 |
| —— VI. | ——— 30 to 46 feet span | 223 |
| —— VII. | ——— 46 to 60 feet span | 224 |
| —— VIII. | ——— 60 to 90 feet span | 224 |
| —— IX. | ——— 55 to 65 feet span | 225 |
| —— X. | ——— 70 to 80 feet span | 225 |
| —— XI. | ——— with Curved Ribs, 20 to 32 feet span | 225 |
| —— XII. | ——— 35 to 100 feet span | 226 |
| —— XIII. | ——— Binding Joists to carry a Ceiling only | 227 |
| —— XIV. | ——— Purlins for Roofs | 227 |
| —— XV. | ——— common or small Rafters | 228 |
| —— XVI. | ——— Story Posts | 229 |
| —— XVII. | ——— ditto | 229 |
| —— XVIII. | ——— ditto | 230 |
| —— XIX. | ——— ditto | 230 |
| —— XX. | The Modulus of Elasticity, Cohesive Force, &c. of Timber | 231 |
| —— XXI. | The Specific Gravity and Weight of a Cubic Foot of Woods | 232 |
| —— XXII. | ——— various Substances | 234 |

# ELEMENTARY PRINCIPLES

OF

# CARPENTRY.

## INTRODUCTION.

ART. 1. CARPENTRY is the art of combining pieces of timber for the support of any considerable weight or pressure.

The theory of carpentry is founded on two distinct branches of mechanical science: the one informs us how strains are propagated through a system of framing; the other how to proportion the resistance of its parts, so that all may be sufficiently strong to resist the strains to which they are exposed. The one determines the *stability of position*, the other the *stability of resistance*. Each of these will be considered in the most simple manner the subject will admit of, with the addition of rules and practical remarks.

Timber is wrought into various forms according to the principles of geometry; and these forms are to be preserved in their original shape only by adjusting the stress and strain according to the laws of mechanics. Hence the importance of studying both these sciences is evident, and particularly the latter; as, without the stress and strain be accurately adjusted, the most careful attention to geometrical rules, and the most skilful workmanship, will be exerted in vain. For instance, if the centre of an arch were to be drawn and worked ever so truly to the curve required, what would it avail if the centre changed its form with every course of stone laid upon it? And it must be remarked, that this is not an imaginary case, but one that has frequently happened; and not only to men ignorant of mechanics, but also to some of the most celebrated engineers that France ever produced.

The engineers of our own country have been more successful; they have succeeded in gradually improving a better principle of constructing centres, than any of the numerous ones designed by the French engineers. The greatest defect of the English centres is an excess of strength, which on principles of economy it would be desirable to avoid.

2. The stability of position is determined by that part of mechanical science which treats of the pressure and equilibrium of bodies. Its application to the carpenter's purposes has been effected in the most clear, simple, and useful manner, by Professor Robison, in the article Roof in the Encyclopædia Britannica, and Carpentry in the Supplement to that valuable work. To the latter article in particular I am indebted for assistance in the following pages. But though Professor Robison treated the subject in the most popular and simple manner, the greater part of the principles and rules in his articles had been investigated before by Emerson, in his *Mechanics, Fluxions, Algebra*, and *Miscellanies.*

3. The stability of resistance is determined by that part of mechanical science which treats of the resistance of solid bodies. And notwithstanding the valuable accessions which the theory of carpentry had received from the labours of Emerson, and the excellent articles by Professor Robison, the carpenter was not able to reap much benefit from them till the importance of the laws of flexure was developed by Dr. Thomas Young, in his *Lectures on Natural Philosophy.* It is true some of the continental mathematicians had been occupied before in researches relative to the flexure of columns; but their method is embarrassed with so many difficulties, and so intricate in itself, that human care was scarcely capable of preventing errors from creeping into their investigations.

By adopting a more simple and elegant method, Dr. Young has established many important principles relating to the flexure of bodies. But still something more simple appears to be wanted for the carpenter's purposes; a work that, without aiming at refined mathematical demonstration, should indicate the sources from which its rules may be derived. Such a work, I hope, this will be found; at the same time, from its being confined to subjects connected with carpentry, the same information may be gained at less expense than from books where the subject of carpentry is only treated of in as far as it is connected with philosophy and science.

# SECTION I.

## OF THE EQUILIBRIUM AND PRESSURE OF BEAMS, OR THE STABILITY OF POSITION.

4. It is through a knowledge of the composition and resolution of forces alone that the carpenter can expect to arrive at excellence in the art of designing frames of timber, for the purpose of building, for machines, and other uses; as without this knowledge it would be impossible for him to understand clearly what is to be aimed at in such designs; or even to know whether a design of his own would answer its intended purpose or not.

The first step towards obtaining this knowledge, is that of acquiring just notions of the action of forces.

5. A heavy body always exerts a force equal to its own weight, in a vertical direction; and would always descend in a vertical line, if not forced out of that direction by some other force.

6. But when a heavy body W (*Plate* I. *fig.* 1) is sustained by two beams AC and BC, its effects on these beams depend on their position; the further the ends A and B are set apart, the greater will be the strains on the beams; and the contrary. Here it is obvious the weight resolves itself into two forces, one in the direction of each beam.

We may now proceed to explain what is meant by the composition and resolution of forces.

### *Of the Composition and Resolution of Forces.*

7. The *resolution of forces* consists in finding two or more forces, which, acting in any different directions, shall have the same effect as any given single force. For the weight W (*fig.* 1) might be sustained by a vertical force in the direction *c*C equal to the weight, and this vertical force, it is obvious, may be resolved into two forces in the directions of the beams that would produce exactly the same effect as the vertical force C*c*.

8. The *composition of forces* consists in finding one force that shall produce the same effect as two or more forces acting in different directions. This is nothing more than the reverse of the resolution of forces, and may be accomplished in the same manner.

9. If a vertical line C*c* (*fig.* 1) be drawn through the centre of the weight, and *a c* be drawn parallel to the beam AC; also *b c* parallel to BC; then, the relations between the weight and the pressures will be found by the following proportions:

As the line C*c*,
Is to the line C*b*;
So is the weight W,
To the pressure in the direction of the beam A*c*.
Also, As the line C*c*,
Is to the line C*a*;
So is the weight W,
To the pressure in the direction of the beam CB.

To those who are acquainted with the principles of mechanics the truth of the principle, from which these proportions are derived, requires no illustration; but such as have not had the advantage of that branch of learning, may, by having recourse to the following simple experiment, not only satisfy themselves of its truth, but also render themselves more familiar with the nature of forces *.

10. Let a thread or fine line be passed over the pulleys B and *c* (*fig.* 2;) and let a known weight be attached to each end of the line, as at *b* and *c*; also let another thread be knotted to the first one at any point A, and attach a known weight to the end W. Then, if the sum of the weights *b* and *c* be greater than the single weight W, there is a certain position in which the assemblage will be at rest; and if it be deranged by pulling at any of the weights, it will return of itself to the same position when left at liberty. Therefore, in that position, and in that position only, the weights will balance one another, or be in equilibrio. Now if the positions of the threads, when the weights balance one another, were drawn upon paper; and, from a scale of equal parts, AF were made equal to the number of pounds in the weight W, and the line BA were continued to E, and the line FE drawn parallel to AC; then FE measured by the same scale of equal parts would show the number of pounds in the weight at *c*; also the measure of the line AE would be equal to the number of pounds in the weight *b*.

If the three weights be equal, then the three lines AF, FE, and AE will be equal, and the angles formed by the threads round the knot will be equal.

11. And, universally, whenever the directions of three forces are in the same plane, and meet in a point, and are in equilibrio, those forces will be represented in magnitude by the three sides of a triangle drawn parallel to the directions of the forces.

12. Consequently if a body be kept at rest by three forces, and any two of them be represented in magnitude and direction by two sides of a triangle, the third side taken in order will represent the magnitude and direction of the other force.

13. Also, because the sides of triangles are as the sines of the opposite angles †, it

* The reader who wishes to have more scientific information on the subject will find it ably handled in Gregory's Mechanics, vol. i. chap. 2; he may also consult Marat's Mechanics, book i. sect. 1; or Wood's Mechanics, sect. 8.

† Gregory's Trigonometry, page 17.

follows, that when three forces keep a body in equilibrio, each force is proportional to the sine of the angle made by the directions of the other two. Thus, the weight W (*fig.* 2) is as the sine of the angle AEF, the weight *b* as the sine of the angle AFE, &c.

It may, however, be observed, that the designs of framing are always drawn on paper to a scale; hence the proportions of the forces may always be obtained immediately from the figure without the trouble of calculation, and the values of the forces so obtained will be accurate enough for any practical purpose. This method then will be adopted, whenever it is found most convenient, in the following pages.

14. Again, considering the combination of forces in *fig.* 1; let the vertical line C*c* be drawn, and by a scale of equal parts make C*c* equal to the number of pounds, hundred weights, or tons, contained in the weight W. Then draw *c b* parallel to BC, and *c a* parallel to AC; and C*b*, measured from the same scale, will show the number of pounds, hundred weights, or tons, by which the beam CA is strained; and, in like manner, C*a* will be the measure of the strain on the beam CB, in pounds, hundred weights, or tons. The pressure is not altered by making the beams longer or shorter, so long as their positions remain the same; but the power of a beam, to resist pressure, is much lessened by increasing its length. But the effect of this power will be considered in another part of the work (see Section II. art. 125.) Only here it may be remarked, that when one beam is much longer than another, in a system of framing, the position of the line of direction of the weight will vary a little from its intended position; because a beam of ten feet in length will compress twice as much as one that is only five feet long, which must cause a corresponding change in the directions of the forces. Also if a beam that has to sustain a pressure in the direction of its length be joined in several places, it will yield more than one that has no other joints than those at its ends; and the yielding will be nearly in proportion to the number of joints, supposing them all to be equally well made; for it is impossible to make a joint that will not yield in some degree.

Changes of form in an assemblage, or system of framing, almost always increase the power of the weight, and often produce cross-strains that are attended with the worst consequences when such changes are not foreseen, and provided for accordingly.

### *Effect of Position.*

15. If the position of the beam CB (*fig.* 1) were changed to that shown by the dotted lines CE, the magnitude of the strain would be prodigiously increased on both beams. By drawing lines parallel to the beams in this position, expressing the weight by the line C*c* the same as before, then the pressure on the beam in the position CE will be measured by the line C*d* instead of C*a*, being much increased; while the strain on the beam CA will be nearly doubled, being represented by the line C*e*.

Hence it appears that enormous strains may be produced by a comparatively small weight, merely by altering the position of the supports. The reader will do well to consider these changes with attention, and to draw figures in different positions, estimating the pressures according to each position; which will render his mind familiar with the subject; and enable him, in practice, to form accurate notions of the magnitudes of pressures, without the labour of calculation.

### *To measure the Strains in a Framed Truss.*

16. If, instead of placing the weight on the point where the beams meet, the beams were framed into a piece of timber, CE (*fig.* 3) and the weight W suspended at E; the pressures would still be propagated in the same manner, and would be found by the same means; Cc representing the weight, C*b* the pressure in the direction of the beam CA, and C*a* the pressure in the direction of the beam CB.

In this case CE performs the office of the king-post in a roof.

17. Hitherto the ends of the beams, marked A and B, in *fig.* 1 and 3, have been considered to be supported by an immoveable obstacle, but they obviously have a tendency to spread; therefore they might be connected by a rope, a rod of iron, or another beam; which would answer a purpose nearly similar to the tie-beam of a roof. It is not quite the same, because a tie-beam has in general to support a ceiling, which a rope or rod of iron would not be sufficient to do.

Let *fig.* 4 represent an assemblage of this kind, where AB is the tie to prevent the lower ends of the beams AC, and CB, from spreading. This form is similar to the truss of a roof.

The strain on the tie AB may be found by drawing *bf* parallel to the tie AB; then, if C*b* represent the pounds or tons with which AC is pressed (found by art. 14;) *bf*, measured from the same scale of equal parts, will be equal to the strain in the direction of the length of the beam or tie AB in pounds or tons. And the equal and opposite strain at B is measured by *e a*.

### *Of Framed Levers.*

18. Let *fig.* 4 be inverted, and supported at C, as represented in *fig.* 5; and a weight hung at each end, so as to balance one another; then the proportion of the strains would remain precisely the same; and it shows how a powerful lever may be framed, and also makes us acquainted with the nature of the strains produced in a solid beam when it performs the office of a lever. The tie AB is in a state of tension, the beams AC and BC are compressed; in a solid beam the same thing takes place, the side next the sup-

port is always compressed, and the opposite side is always in a state of tension. Thus we see the same general principle regulates the equilibrium of matter in all cases, and that all forces act by the same laws; which naturally leads us to admire the wisdom of our Creator, who has, by the same simple, and yet general property of forces, accomplished such a wonderful series of effects.

It may be observed, that when the frame is inverted, as in *fig*. 5, and the tie AB is perfectly straight, there is no strain on the piece CE. But if the tie were of the form shown by the dotted line AgB, then the piece gEC would be compressed; and, on the contrary, if the tie were of the form represented by the dotted line A*h*B, the piece *h*C would be in a state of tension, or drawn in direction of its length. It is the same with a solid beam; as when it becomes bent in any considerable degree new forces are called into action, and it always bends considerably before breaking; consequently, rules that do not include the effect of the forces that are brought into action, by the bending of a beam, cannot perfectly agree with experiments. The investigation of the stiffness of beams, which is the most useful to the carpenter, being confined to the first degrees of flexure, is not liable to this objection.

### *Effect of Position further considered.*

19. To take another example; let *fig*. 6 represent a frame fixed against a wall, and let the weight be suspended from the point C, where the beams CA and CB join. In this assemblage, the beam AC will be stretched, and the beam CB will be compressed; or, in other words, AC will act as a tie, and CB as a strut.

To estimate the quantities of the pressures, draw the line C*c* in the direction in which the weight would move if left at liberty, that is, in a vertical direction; then, from a scale of equal parts, set off C*c* equal to the weight in pounds; from *c*, draw *c b* parallel to CA; and C*b* will represent the force pressing on the beam CB; also, *c b* will represent that stretching CA, which being each measured by the scale will give the values of these strains in pounds.

If the position of the beams in *fig*. 6 were changed to that shown in *fig*. 7, the beam BC would still act as a strut; that is, the weight would have a tendency to compress it: this is evident, because, notwithstanding its inclined position, its place could not be supplied by a rope, which would be the case if it were only stretched.

Also, in *fig*. 8, AC is in a state of tension, and its place might be supplied by a rope, though it appears from its position to act as a strut. In either of these cases the magnitudes of the strains are to be estimated as in *fig*. 6. As the line representing the weight is the same in each, by comparing these figures it will be seen how much the pressures are increased by altering the position of the beams.

20. The last three figures are each similar to the jib of a crane, but the strain upon the jib of a crane is very different: this difference I will endeavour to explain, and in so doing will point out some principles that ought to be attended to in the construction of jibs.

Let DCE represent the rope by which the weight is raised (*fig.* 9) passing over a pulley at C; it is clear that the strain in the direction CD is equal to the strain in the direction CE; but in each of the cases represented in *fig.* 6, 7, and 8, the strain was in the direction CE only.

Now if we make CE equal to CD; and draw BE parallel to DC, cutting the line DB in B; then, joining BC, we have the direction of a beam that would sustain the forces in the directions DC and EC: and the beam placed in the direction BC would sustain the whole effect of the strains with the least force possible; only requiring a piece AC to steady it.

But when the beam BC is placed in any other position than that found by constructing a parallelogram on the directions of the ropes, the effect of the straining forces will be increased; and will vary according to the position of the sustaining beams. For example, let the beam BC be removed to the position shown by the dotted lines $B^1C$. Then both AC and $B^1C$ will be in a state of compression. Let the vertical *Ca* represent the weight W, then *Cb* will represent the force in the direction of the beam in the position $CB^1$; and *b c*, that compressing the beam AC, from which the equivalents of these forces in pounds or other weights may be ascertained.

Again, suppose the beam BC to be removed to the position shown by the dotted lines $B^2C$, instead of $B^1C$; then it would be compressed, and the strain nearly doubled; while the beam AC would be in a state of tension, under a considerable strain. This is of all others the most defective form for a crane jib; yet it is that which is most commonly used. When CA represents the weight W, *Ce* represents the pressure on the beam $B^2C$; and *c e* the tension on the beam AC; and being compared, with the same line to represent the weight, in each case we see how devoid of principle the usual methods of construction are, as well as the obvious means of improvement.

21. The beam BC, in the jib of a crane, is called the *spur;* and the position, so that it shall be the best adapted for the purpose, appears to be, to place it a little below the diagonal of a parallelogram, constructed on the directions of the ropes. This diagonal may be found as follows: Let DF be the shaft (*fig.* 10, *Plate* II.) and DC, CE, the directions of the ropes for raising the weights. Make CA equal to CG; and draw BG parallel to AC, and AB parallel to CG; then join CB, and it is the diagonal required. Then, to place the foot of the spur a little lower than the point F, where the diagonal cuts the line of the shaft, causes both the spur and head-piece to be compressed, and produces the strongest arrangement, and one that will move more steadily than any other.

It is scarcely necessary to state, that in all these cases the beams have been supposed

to be capable of motion at the joints, or points of connection; as all the firmness that can be given at the joints is so very small in heavy framing, that its effect, in all cases where calculation is necessary, may be left out of the question. The methods of connecting or joining framing will be considered in a separate section. (See Sect. IX.)

*To distinguish Ties from Struts.*

22. It is necessary, in estimating the strength of framing, that we should be able to distinguish the struts from the ties; that is, to ascertain which of the beams are compressed, and which of them are stretched. By attending to the following considerations, this may be easily determined. From the point on which the straining force acts, draw a line in the direction the force would move in, if the framing were removed. When this line falls within the angle formed by the pieces strained, then both pieces are compressed. But when it falls within the angle formed by producing the directions of the sustaining pieces, then both the pieces are in a state of tension.

The following method is a more general one, and includes the case just stated.

23. Let a parallelogram be constructed, on the direction of the straining force as a diagonal; the sides of the parallelogram being parallel to the sustaining forces; then, let the other diagonal of the parallelogram be drawn; and parallel to it, draw a line through the point where the directions of the forces meet. Consider towards which side of this line the straining force would move if left at liberty; and all supports on that side will be in a state of compression, and all those on the other side will be in a state of tension.

The same thing would be true of a plane passing through the point where the forces meet, when three or more forces meet that are not in the same plane; but such cases are of rare occurrence; therefore, I shall only apply it to the examples in *fig.* 3, 6, and 7, *Plate* I. which will enable the reader to apply the method to all cases where the sustaining forces are in the same plane.

In *fig.* 3, 6, and 7, *Plate* I. C*c* is the direction of the straining force, on which as a diagonal the parallelogram C*bca* is drawn, the sides of it being parallel to the resisting or sustaining beams: join *ba*, and draw the dotted line *ee'* parallel to *ba* in each figure; then, in *fig.* 3, the straining force would move towards E, if left at liberty; therefore both the beams are compressed, being both on that side of the line *ee'*.

In *fig.* 6 and 7, only the lower sustaining beams are compressed, the upper ones are extended; and if the line *ee'* were drawn to *fig.* 2, it would show that both the supports are in a state of tension.

*To find the Resultant of a System of Forces.*

24. As the strain upon a piece of framing is often produced by two or more forces, acting in different directions, of which the crane is an instance, the means of finding a force and its directions that would be equal in effect to two or more forces may be next considered a little more attentively. In all cases where the strain is produced by the action of several forces meeting in one point, these forces must be reduced to a single force, capable of producing the same effect; otherwise it will not be possible to determine the strain upon the supports.

25. A force capable of producing the same effect as two or more forces, is called the *resultant* of those forces.

Let AC represent the magnitude and direction of a force, acting on the body C, (*Plate* II. *fig*. 11,) and BC the magnitude and direction of another force also acting on the body C. Then to find the resultant, draw *b*B parallel to AC; and A*b* parallel to BC; join *b*C, which represents the resultant required. The lines connecting the points A, C, B, *b*, form a parallelogram, of which *b*C is the diagonal; and whenever two sides of a parallelogram are parallel to the directions, and proportional to energy of two forces, the diagonal will represent the direction and energy of a force that would produce the same effect. A parallelogram constructed in this manner is called a *parallelogram of forces*.

Also, if the force *b*C were to act in the opposite direction, that is, from *a* towards C, it would retain the two forces AC and BC in equilibrio; but two forces only can never be in equilibrium unless their directions be exactly opposite, and the forces equal; and the direction they would move in when not exactly opposite, is shown by producing the diagonal of the parallelogram drawn on their directions. Thus C*a* (*fig*. 11, *Plate* II.) is the diagonal produced; and consequently the direction in which the forces AC and BC would cause the body C to move.

26. If it were required to find the resultant of three forces pressing on the point C, of which the magnitudes and directions were represented by the lines AC, BC, and DC, (*fig*. 12, *Plate* II.) In the first place complete the parallelogram BCD*b*, as in the preceding example; from which we find *b*C to be the resultant of the two forces BC and DC. Then consider *b*C and AC as two forces, and complete the parallelogram A*ab*C, and *a*C is the resultant required; that is, a force, the magnitude and direction of which is represented by *a*C, would produce the same effect in moving the point C as the three forces AC, BC, and DC. Also, a force equal to *a*C, and opposite, would keep these three forces in equilibrio.

By pursuing the same method of reduction, the resultant of any number of forces

tending to one point may be found; but the same thing may be effected more simply as follows:

27. Let AC, BC, and DC, *fig.* 13, be the three forces*; beginning at any force, as at B, make B$a$ parallel and equal to the next force DC; and then make $a\,d$ parallel, and equal to the other force AC; join $d$C, and it is the resultant of the three forces.

The figure B$ad$C is called the *polygon of forces*, and the number of its sides will always be one more than the number of the forces.

28. When any strain is produced by a single force it is sometimes useful to know its effect in a particular direction, in order to apply an equivalent support in that direction. Thus, when a force acts obliquely against the plain surface of an immoveable obstacle, the force will have a tendency to slide along the plane; because two forces cannot sustain each other unless they be equal and opposite. Let a force AC, *fig.* 14, act upon the even surface of a plane CB; it is evident that only part of this force will be exerted in a direction perpendicular to the plane, and this part will be represented by the line AB, drawn perpendicular to the plane; and then, CB will represent the force that would prevent it sliding along the plane.

When two pieces of timber are joined obliquely, the pressure on the different parts of the joint may be ascertained by this method; for example, let DB, *fig.* 15, represent the end of a tie-beam, and AC the principal rafter; the force in the direction of the rafter being represented by AC. Then AB being perpendicular to the part C$a$ of the joint, will represent the pressure upon it, and the pressure on the part C$d$ will be represented by CB; consequently CB will be the measure of the force tending to splinter off the part D. (See Sect. IX. on Joints.)

We cannot often oppose a force by one directly opposite, but we can generally find two forces that will answer the purpose; and by constituting a triangle on their directions, and that of the force to be supported, their proportions can always be ascertained. This principle is the most important one in the theory of carpentry.

29. In general the designs for framing may be so contrived, that the load rests upon two or more points; for example, the weight of a roof acts on the truss which supports it, only at the points where the purlins bear upon the truss; and when these points are supported by struts, the forces may be considered, without material error, to be in the direction of the principal rafters. But when the load is uniformly distributed over the rafter, and it is supported at the ends only, the strain upon the tie-beam is no longer in the direction of the rafter: and as there are some important strains produced by the action of uniform loads, the nature of these strains will form the next object of inquiry.

* Where forces are represented in magnitude and direction by lines, the lines only are used for the sake of clearness and conciseness to express the forces.

In order to render the inquiry more clear and simple, let the load be supposed to arise from the weight of the beams themselves.

### *Of the Centre of Gravity.*

30. In a heavy beam there is a single point, by which it may be supported; and if so supported, it may be placed in any position, and remain at rest. Whereas, were it supported by any other point, it would rest only in certain positions.

This point is called the *centre of gravity* of the beam.

A beam AB, suspended by a pin at C (*fig.* 16, *Plate* II.) passing exactly through the centre of gravity will rest in the position AB; or in that shown by the dotted lines *a b*, or any other. And the same thing will have place let the body be ever so irregular, provided the support passes exactly through the centre of gravity.

The centre of gravity of an uniform cylinder or prism, is at the middle of its length.

In a triangle the centre of gravity is in a line drawn from the vertex to the middle of the base, and at the distance of one-third of that line from the base.

In cones or pyramids the centre of gravity is one-fourth of the height from the base.

The place of the centre of gravity in various planes, lines, and solids, has been determined by mechanical writers; and as the subject is considered in most works on mechanics*, it is not necessary to enlarge upon it here; because when the rules become complicated it is easier to ascertain it by mechanical means, and in irregular figures such contrivances must be resorted to.

The most useful mechanical methods of finding the centre of gravity are the following;

31. To find the centre of gravity of a body with plain sides, suspend it by the cord AEB, *fig.* 17, fixed to the body at A and B, and passing over a pin E. When the body is at rest by means of a line and plummet, draw a plumb or vertical line upon it, as at *a b*. Then, slide the cord upon the pin E, so as to change the position of the body as much as possible; and when it is at rest again, draw another vertical line upon it, and where this vertical line crosses the former one will be the centre of gravity of the body.

32. Another method. Balance the body upon the edge of a triangular prism (see *fig.* 18), and mark a line upon it close by the edge of the prism; then change the position of the body upon the prism, balance it again, and a line drawn by the edge of the prism will cross the former one, and the point of intersection will be the place of the centre of gravity of the body.

* See Gregory's Mechanics, vol. i. chap. iii.; or Marat's Mechanics, book i. sect. iii.

The intersecting lines should cross each other nearly at right angles if possible, as the nearer they cross at right angles the more accurately the point will be found.

The same thing may be done by laying the body upon a bench, and moving it so as to balance over the edge, or till it be just on the point of falling off. Then mark a line along by the edge of the bench, and do the same in another position, which will in like manner determine the centre of gravity.

33. It is a principle in mechanics, that when a body is supported and at rest, the directions of the supporting forces must either meet at the centre of gravity, or in a vertical line passing through it, except the forces be parallel to one another*.

34. And when a body is supported by one or more planes, and the body is at rest, the pressure on the planes is in a direction perpendicular to their surfaces; when the pressure upon the plane is in an oblique direction, the body will not remain at rest, unless it be in consequence of the friction of the surfaces, which is neglected in this inquiry.

By the help of these principles it will be easy to determine the direction of the pressures produced by a heavy beam or other body in some of the most useful cases.

### *Of the Pressure of Inclined Beams.*

35. Let AB be a beam, *Plate* II. *fig.* 19, resting against the vertical wall BD, and C its centre of gravity; the lower end resting on an abutment cut in the beam AD. Through the centre of gravity C, draw the vertical line *c e*; and draw *c*B perpendicular to BD, meeting *c e* in *c*. Join A*c*, which will be the direction of the pressure against the abutment at A; and that the beam may have no tendency whatever to slide, the abutment should be perpendicular to A*c*.

Also, if *c e*, taken from a scale of equal parts, represent the weight, and *a e* be drawn parallel to *c*B, then *a e* will represent the pressure against the wall at B, and *c a* the pressure against the abutment at A. The horizontal thrust at the abutment A, is also measured by the line *a e*; as it is always equal to the horizontal pressure against the wall at B. The pressures of shed or lean-to roofing are shown by this example.

36. Let AD be a smooth horizontal plane, and BD a smooth vertical plane (*Plate* II. *fig.* 20;) the force which the end A, of the beam AB, would exert in a horizontal direction in any position of the beam, may be found by the equation $\frac{W \times m \quad \cos. a}{h} =$ the horizontal thrust. Where W is the weight of the beam, $m$ the distance of the centre of gravity AC from the lower end; $a$ the angle which the beam forms with the horizon; and $h$ the height BD of the upper end of the beam.

* Gregory's Mechanics, vol. i. art. 106.

It is evident from this equation, that when the weight is the same, the length of the beam does not alter the horizontal thrust, while the angle of inclination and distance of the centre of gravity are not varied. And that the horizontal thrust increases in proportion to the distance of the centre of gravity from the lower end, and that it also increases as the angle of inclination decreases.

37. It has been already stated, that the abutment should be perpendicular to the direction of the pressure (art. 35;) and it may be shown that the tangent of that angle which the abutment for the lower end should form with the horizontal plane is equal to $\frac{m \times \cos. a}{h}$; which becomes $\frac{\text{AD}}{2h}$ when the centre of gravity is at the middle of the length of the beam. Hence the angle may be easily calculated.

38. When the beam moves between the planes, so that the lower end slides along the plane AD, *fig.* 20, and the upper end down the plane BD, the centre of gravity C will describe a portion of an ellipse of which BC will be the semi-transverse, and AC the semi-conjugate axis. And when the centre of gravity is in the middle of the length of the beam, it will describe a circle; of which the radius is equal to half the length of the beam*. This curious property may in many cases be applied to describe an ellipse on a large scale with advantage, as it is simple and easy to put in practice almost in any situation. The line in *fig.* 20 shows the part of an ellipse so described.

39. When two similar and equal beams AD and DB, are placed in the position represented in *fig.* 21; CC′ being their centres of gravity; then their pressures against each other, at the point where they meet, will be equal and opposite; and their horizontal thrusts will also be equal, and may be found by art. 35 and 36; as each beam is obviously in the same state as that in *fig.* 19.

As the horizontal thrust of a roof is nothing more than a particular case, which is easily solved by the same rules, I will give the equation in art. 36, in words at length, with an example of its application to that purpose.

40. RULE *for the Horizontal Thrust of an inclined Beam.* Multiply the weight in pounds by the cosine of the angle of inclination; and multiply this product by the distance, in feet, of the centre of gravity from the lower end; divide the last product by the height DE in feet, and the quotient will be the horizontal thrust in pounds.

*Example.* Let the weight diffused over the length of a rafter be 1600 lbs. The angle of inclination 27 degrees, of which the cosine is ·891; and the distance of the centre of gravity from the lower end, 7 feet; the rise or height DE being 6 feet 6 inches, or 6·5 feet.

Then, $\frac{1600 \times \cdot 891 \times 7}{6 \cdot 5} = \frac{9979 \cdot 2}{6 \cdot 5} = 1534$ lbs. nearly for the horizontal thrust, which is not much less than the weight in this particular case.

* Edinburgh Review, vol. vi. p. 387.

When the centre of gravity is at the middle of the length of the rafter, the rule becomes more simple, and may be stated as follows:

RULE, when the centre of gravity is at the middle of the length of the rafter or beam. Multiply the weight in pounds by the distance AE, in feet, (which in a roof is half the span), and divide the product by twice the height DE, in feet, and the quotient will be the horizontal thrust.

*Example.* The weight uniformly distributed over a rafter is 200 lbs.; the span of the roof is 20 feet, half of which is 10 feet; and the height of the roof is 5 feet. Then, $\frac{200\times 10}{2\times 5}=200$ lbs. the horizontal thrust, which is exactly the same as the weight, and will always be so when the roof rises exactly one-fourth of the span, but not in other cases.

41. Let us now suppose a weight to be laid on at D, in *fig.* 21, its effect would be to press the beams in the directions of their lengths, as has been shown, and the magnitudes of these pressures may be found by the former articles (see art. 6 and 14.) Hence we see that a beam performing the part of a strut or an oblique support is often strained by two forces, the one being caused by the weight supported, and the other by the weight of the beam itself, or some uniform load. But it is a well ascertained fact, that a beam pressed in the direction of its length is very much weakened by a cross strain of this kind. If a beam happens to have a slight natural curvature, the convex side should be placed upwards, which will counteract the effect of the weight of the beam.

42. It is easy to alter the directions of the pressures of a beam by altering the position of the supporting surfaces. If, for example, the beam AB, *fig.* 22, were cut so as to rest upon two level plates at A and B, the beam would have no tendency whatever to slide, notwithstanding its inclined position, and consequently it would have no horizontal thrust. The carpenter may in many cases take advantage of this circumstance in preventing oblique strains upon the points of support, for those supports may be abundantly strong to resist a perpendicular pressure, and yet be incapable of sustaining a very small force in an oblique direction.

The present example shows that by cutting the rafters of a shed roof so that they may rest level upon the plates, the roof will have no tendency to push out the lower wall.

43. To find the perpendicular pressure upon the points of support, draw the horizontal line $a\,b$ through G the centre of gravity of the beam.

Then, $\frac{W\times bG}{a\,b}$ is equal to the pressure on A,

And, $\frac{W\times aG}{a\,b}$ is equal to the pressure on B*;

Or, as $bG : aG ::$ pressure on A : pressure on B.

* Gregory's Mechanics, vol. i. art. 80.

The relations between the weight W, and the pressures on the points of support, are the same in a straight beam, laid in a horizontal position upon two supports, *fig.* 23.

### *Of the Strain upon Beams laid horizontally.*

44. When a beam is laid in a horizontal position, as in *fig.* 23, and a load is uniformly distributed over its length, or the beam is only loaded by its own weight, the strain upon the beam is the same as if half the weight were acting at its centre of gravity.

But if the weight be distributed over the beam it must be of a yielding nature, otherwise this rule will not hold good. If a strong short beam be laid upon the first beam, and the weight upon that, the strain upon the lower beam would be removed to the points where the ends of the short beam would rest upon the longer one, and of course the strength of the longer one would be much increased.

45. When a beam is supported at the ends, as *fig.* 24, the stress arising from any weight, W, produces the greatest strain when it is applied in the middle of the length. And, if $w$ be the greatest weight the beam would support in the middle, the greatest weight W that it could support at any other point C, will be found by the following proportion:

As the distance AC multiplied by the distance BC,
Is to the square of half the length of the beam;
So is the weight $w$, that could be supported in the middle,
To the weight W that could be supported at the point C.

From whence it appears, that a beam 20 feet long will bear double the weight, at 3 feet distance from one end, that it would bear in the middle of its length. Consequently the further a load can be removed from the middle of the beam the better; and when it is necessary to place the stress at or near the middle, it is of great importance to cut the timber as little as possible with mortices at the point where the stress acts, and the piece should be as free as possible from knots in that point. Also, as a beam is generally weakest at the point strained, the same precautions should be attended to wherever the strain may be.

46. If $w$ be the greatest weight a beam whose length is L will bear in the middle of its length, and it be required to support by that beam any greater weight W, the point C may be found by this equation, $\frac{L}{2} \times (1 \pm \sqrt{\frac{W-w}{W}}) =$ the distance of the point C from the ends. The upper sign gives the distance from the remote end, the lower sign gives the distance from the nearest end.

### *Of the Equilibrium of an Assemblage of Beams.*

47. When an opening is too wide to be spanned with one or even two pieces of timber, it may be effected by a combination of pieces which bear a near resemblance to an arch in masonry; the principles of stability are not, however, exactly the same. In a piece of carpentry the stability is gained by the strength of the material, and the mode of connection; in a stone arch the stability is gained by a proper disposition, and depth of the joints. The principles of equilibrium, as established by mathematical writers, are better suited to the kind of construction employed in carpentry, than to a stone arch; but it requires some modifications which have only lately been found to be necessary*. When a combination of beams is strained by a force which tends to destroy the balance of its parts, if the strain at any part be examined, it will be found to be of two kinds; the one stretching, the other compressing: and in the depth of the framing there will be one point in a neutral state, in the same manner as in a solid beam. Now the curve of equilibrium should pass through the neutral points, and not form the inner line of the system of framing, as Emerson, Hutton, and others assert†. If the combination consisted of single frames, or blocks, without connection, but merely abutting against each other, the forces excited by a strain on any part would be wholly of the compressive kind, as it is in a stone arch; and in this case we have not a satisfactory investigation of the laws of stability. But in a combination of beams, to lose the advantage of connection, is to lose that in which the excellence of the carpenter's art chiefly consists; therefore the latter case need not be considered.

### *Of the Points of Fracture in a System of Framing.*

48. The balance of the parts in a system of framing is not so complicated a question as it is generally imagined to be; at least it is not so while our inquiries are confined to practical cases. A system of framing for spanning a wide opening is generally composed of two equal and symmetrical parts; and when it is loaded, the load is also similarly disposed. When the parts are loaded so as not to be in equilibrio, the system will divide itself into four parts only, and not more.

49. Again, if the system be balanced, and rupture be produced by a weight laid on at any particular point, the system may either divide itself into three or four parts. When the weight is laid upon the system at or near the middle of the span, it will

* Encyclopædia Britannica, Supplement to 5th edition, art. Bridge.

† Emerson's Fluxions, sect. ii. prob. 20; Hutton's Principles of Bridges.

divide itself into four parts. When the weight is laid upon it at some distance from the middle, the framing will generally divide itself into three parts.

50. Let *fig.* 25, *Plate* III. represent a system of framing, which is similar to one applied by Mr. Seppings, for the roof of a dock for building ships under cover*. The parts of this roof are obviously not in equilibrio, and the weight of the roof itself tends to cause fracture at the points B, C, and B′, consequently to break the roof into four parts, AB, BC, CB′, and B′A′.

The uprights AB and A′B′, have neither position nor weight to balance the spread of the superior parts; and the stability of the system depends wholly on the strength of the post to resist a cross strain, and the connection of the parts. By a proper disposal of the parts of this roof, the greater part of the strain arising from the weight of the roof itself might have been removed; and of course the roof would be much stronger to resist any other force, such as the wind, &c.; or it might have been constructed with less material and labour.

I have cited this example to show that it is as essential that the principles of equilibrium should be known, as it is to understand the best method of stiffening and connecting the parts. The roof of Mr. Seppings is a fine example of the latter, and it has undoubtedly been for the purpose of leaving as much free space as possible, that the upright posts only were used; for an oblique strut in the direction *a*B would have added much to the stability of the frame†.

51. To find the position of the side posts so that the roof may be in equilibrio. Let G be the centre of gravity of that part of the frame between B and C, *fig.* 26. Draw the vertical line *bg* through G, and from the middle of the depth of the framing at C, draw the horizontal line C*b*, cutting the vertical line in *b*. Then draw the line AB*b*, and AB is the position of the post.

Here no notice is taken of the weight of the post itself, because it is too small to produce a sensible difference in the position.

52. In *fig.* 25, B, C, and B′, may be called the points of fracture, or the centres of motion, which in this case are easily found by inspecting the figure. In general it is more difficult to ascertain their position, and they are affected by so many circumstances, that it is not practicable to give a general rule for finding them.

But in most cases, the positions of the centres of motion may be determined, with all the accuracy required in practice, by inspection; and it may be as well to illustrate this point before proceeding to examine these combinations further.

* The roof designed by Mr. Seppings is 95½ feet span from A to A′; it is described in the Supplement to the Encyclopædia Britannica, art. Dock, p. 590.

† In another department of carpentry, viz. ship carpentry, Mr. Sepping has introduced some improvements which promise to be of great service. The improvement consists in applying diagonal braces to strengthen ships. See Phil. Trans. for 1818, part i.

In the first place, suppose ACB, *fig.* 27, to be a solid curved beam, resting on the abutments A and B. Let it be uniformly loaded and the strength equal in every part of its length, then the neutral line would be at the middle of the depth. Now if the curvature of the neutral line should not be the proper curve of equilibrium to the load, there would be a tendency to break at three points, one of which would be at C, the middle of the length. The other points would be near where the neutral line is most distant from the chord line AC and CB, but a little below, that is, at *e* and *f* in the figure.

53. If the beam should be much weaker at any point *b* than it is at *e*, the centre of motion would be in the point *b*, and one of the fractures would be there in the case of failure. But if the weak point were at *d*, the beam would be less liable to fail there, unless it should be very much weaker than at *e*.

54. Again, considering the strength to be equal throughout, and the load to increase from A and B towards C, then the fractures would take place at, or rather above the points *e* and *f*. On the contrary, if the load should increase from C towards A and B, the fractures would be below the points *e* and *f*.

Hence, by attending to the form, the strength of the parts, and the disposition of the load, in a system of framing, the centres of motion, or places of fracture, may be determined with all the accuracy that is necessary in practice.

55. But the constant load on a system of framing may be so balanced by the form of the supporting frame, that it will have no tendency to produce fracture; and then the strength should be capable of sustaining any other load of a variable nature, as the weight of carriages, &c. upon a bridge, or the like. In order that the load may be thus balanced, the form of the supporting frame should be such, that a particular *curve*, which will depend on the nature of the load, may pass through the middle of the depth of every part of the supporting frame. This *curve* is called the *curve of equilibrium.*

The form of the curve may either be found by mathematical investigation, or by mechanical means, when the nature of the load is known.

*To determine the Curve of Equilibrium.*

56. Let AC represent a portion of a curve of equilibrium, *fig.* 28, C being the vertex of the curve, and GE a vertical line passing through the centre of gravity of the load resting upon the part between A and C.

Then by similar triangles AE : GE(=CB) :: AB : BD :: horizontal thrust to the weight. Therefore, $\frac{\text{CB}\times\text{AB}}{\text{AE}}=\text{BD}$. But BD is the subtangent of the curve, con-

sequently when it agrees with that of any known curve, that curve is the curve of equilibrium.

57. *Example* 1. Suppose the load to be uniformly distributed over the framing, then the centre of gravity of the load over any portion AC will be over the middle of AB, and AE will be equal $\frac{1}{2}$AB. Consequently, BD=2Bc, a property of the parabola*. Therefore when the weight is uniformly distributed the curve of equilibrium is a parabola. A method of describing a parabola will be found in the section on roofs, (Sect. IV.) Various other methods are given by writers on *Conic Sections;* particularly in Emerson's *Conic Sections,* book iii. prop. 59 and 60; and an easy method is given by Nicholson in his *Carpenter's Guide,* p. 11.

As in bridges and roofs the weight is very nearly uniformly distributed, it will generally be near enough for practice to use the parabola as the curve of equilibrium; where greater accuracy is required, it may be found by art. 61.

58. *Example* 2. Let the weight on any part of the framing be proportional to the distance from C, the middle of the span.

Then the distance AE will be equal to $\frac{1}{3}$AB; because the distribution of the weight may be represented by a triangle, with the vertex at C, and base at A. In this case BD=3BC, a property of the cubic parabola. Hence, when the weight is distributed in proportion to the distance from the centre, the curve must be a cubic parabola. To describe this curve, put $s$=half the span, and $h$=the rise of the framing; $x$ the absciss, and $y$ the corresponding ordinate. Make $x=nh$; then $sn^{\frac{1}{3}}=y$†.

The curve may also be constructed by the following method:

Divide the rise BC (*fig.* 29) into eight equal parts, and draw the horizontal lines $a$ 1, $b$ 2, $c$ 3, &c. Then the distance

| | | | | | |
|---|---|---|---|---|---|
| AB multiplied by | 0·5 | will be equal $a$ 1, | AB multiplied by | 0·855 | will be equal $e$ 5, |
| AB .......... | 0·63 | .......... $b$ 2, | AB .......... | 0·9085 | .......... $f$ 6, |
| AB .......... | 0·721 | .......... $c$ 3, | AB .......... | 0·956 | .......... $g$ 7. |
| AB .......... | 0·7937 | .......... $d$ 4, | | | |

Through the points $a, b, c, d, e, f, g,$ draw the curve, and it will be the cubic parabola sufficiently near for practice.

59. Whenever the distance of the centre of gravity from A (*fig.* 28) is expressed by

* Vince's Fluxions, p. 36, second edition.

† For by the property of the curve, $ax=y^3$; and, when $x=h$, and $y=s$, $ah=s^3$, or $a=\frac{s^3}{h}$; therefore $\frac{s^3x}{h}=y^3$, or $s(\frac{x}{h})^{\frac{1}{3}}=y=sn^{\frac{1}{3}}$, when $x=nh$.

the equation $AE=\frac{1}{m}AB$, the curve of equilibrium will be a parabola of which the equation will be $ax=y^m$, and the subtangent$=mx$ *.

60. It is useful to know the subtangent of the curve of equilibrium, because it gives the tangent, and consequently the direction of the pressure at the abutment. In any case, where the equation of the curve of equilibrium is $ax=y^m$; the pressure on the abutment will be in the direction of a line, which makes an angle with the horizon, of which the tangent is $\frac{mh}{s}$; where $s$=half the span, and $h$=the rise. And also, when we make $w$=the weight of half the framing, we have $\frac{sw}{mh}$=the horizontal thrust.

61. *Example* 3. When the weight is distributed over a piece of framing, a bridge for example, so that the weight on any portion from the middle towards the abutment shall be represented by a trapezoid AFHC, *fig.* 30, put $HC=a$, which will represent the weight at the middle of the arch; and let $IC : IA :: 1 : n$; then $ay+\frac{1}{2}ny^2$=the weight on any portion of the arch, whose horizontal ordinate is $y$. Put $AB=y$ (*fig.* 28) and $CB=x$, and we have $\frac{3x(ny+2a)}{ny+3a}$=BD the subtangent of the curve. Consequently, when the point A is at the abutment, and $y=s$=half the span, and $x=h$, we have $\frac{3h(ns+2a)}{s(ns+3a)}$= tangent of the angle which the direction of the pressure on the abutment makes with the horizon. And $\frac{s^2}{6h}(3a+ns)$=the horizontal thrust at the abutment.

But in order to construct the curve, its equation should be known; to effect this, put H=the horizontal thrust, and by converting the relations of the forces into an analogy, we easily derive from art. 35, $ay+\frac{1}{2}ny^2$ (the weight) : H :: $x$ : to the distance of the centre of gravity from $A=\frac{Hx}{ay+\frac{1}{2}ny^2}$; but by art. 56, the value of the subtangent $\frac{yx}{\textit{dis. centre of gra.}}=\frac{ay^2+\frac{1}{2}ny^3}{H}$. And, by the principles of fluxions $\frac{y\dot{x}}{\dot{y}}$=the subtangent †, therefore $\frac{ay^2+\frac{1}{2}ny^3}{H}=\frac{y\dot{x}}{\dot{y}}$, whence we have $\frac{y^2}{2H}(a+\frac{1}{3}ny)=x$ for the equation of the curve.

This equation will be sufficiently accurate for determining the form of the curve for most cases; as the expression for the weight will nearly agree with the distribution

* Emerson's Fluxions, p. 203. † Vince's Fluxions, art. 23.

most commonly occurring in practice. The absciss $x$, and ordinate $y$, become $h$, and $s$, at the abutment, and these being always given, we have $H=\frac{s^2}{2h}(a+\frac{1}{3}ns)$; and, H being determined either by this method, or as above, as the equations are actually the same, the ordinates of the curve may be easily calculated*.

The curves that apply to such cases as usually occur in practice are evidently of a parabolic kind; and the same observation applies to those curves which are proper for cupolas, or domes, to which we must now proceed.

*To determine the Curve of Equilibrium for a Cupola or Dome.*

62. Conceive the dome to be generated by the motion of the curve AC (*fig.* 28) round CB as an axis; then the same relations will obtain as in the case of an arch (art. 56,) that is $\frac{CB \times AB}{AE}=BD=$the subtangent of the curve of equilibrium. Let AI be the plan of the dome, *fig.* 31, and let it be divided at the circumference into any number of equal parts, of which HF is one; then, whatever form is necessary to equilibrate the gore HFC′, must be equally requisite for every other part of the dome. Let ACB be a section through A′C′ the middle of the gore HFC′.

63. *Example* 1. When the weight is uniformly distributed.

In this case the weight on any part of the gore is proportional to the distance from the centre; consequently the centre of gravity is $\frac{1}{3}$AB from A: and the curve is a cubic parabola, the same as in Example 2, art. 58; and may be described in the same manner†.

64. *Example* 2. Let the weight be distributed so that the weight on any portion AC, *fig.* 31, is$=ya+\frac{pby^2}{3}$, where $y$ is equal the ordinate AB, $a$ the depth of an uniform weight; and 1 : $b$ the ratio of increase of another part of the load, which increases regularly from the centre to the circumference: also $p=6{\cdot}2832$.

By the same process as in art. 61, we obtain $x=\frac{y^2}{2H}(a+\frac{1}{6}pby^2)$; where $x=$BC the absciss; and H=the horizontal thrust.

* The same equation is used for expressing the weight in prop. S, in the article Bridge, Supplement to the Encyclopædia Britannica; but an error has been overlooked in calculating the equation of the curve.

† The same conclusion is obtained in a different manner by Emerson, Fluxions, p. 333; and by Dr. Hutton, in his Tracts, vol. i. p. 65.

Hence, when the rise and radius of the base of the dome are given, the rise or height being $h$, and the radius $r$, $\frac{r^2}{2h}(a+\frac{1}{3}pbr^2)=H$.

The most useful cases of domes will be determined by this equation, from which it is easy to find a sufficient number of points in the curve to design the framing upon. It is scarcely necessary to remind the reader, that in domes, as in arches, the curve of equilibrium must pass through the middle of the framing.

65. *Example* 3. Suppose the curved part of the dome, *fig.* 32, to be uniformly loaded, and a lantern on the top, the space CD being open.

Let W be the weight of the lantern, and $wpy(y+r)$=the weight pressing on the curved surface AC, where $y$=AB, $r$=CE the radius of the lantern, and $p$=3·1416.

The whole weight is $wpy\ (y+r)+W$, and the equation of the curve of equilibrium is $\frac{y}{H}(\frac{1}{3}wpy^2+\frac{1}{2}wpry+W)=x$.

Let the radius of the base of the dome be $R+r$, and $h$ the height to the base of the lantern. Then, $\frac{R}{h}[wp(\frac{1}{3}R^2+\frac{1}{2}Rr)+W]=H$=the horizontal thrust.

66. From the equations in the two preceding articles, the proper curve for a dome may be obtained; but it may be remarked, that so long as the curve is not more convex towards the external surface than the proper curve of equilibrium, the form may be changed at pleasure; because every part of the framing may be strutted so that it cannot press inwards.

The curve of equilibrium is not the weakest form for a dome, as Dr. Robison states it to be*, but it is the limit that should never be exceeded. The curvature of the line passing through the middle of the framing may be of any form within the middle, and be stronger; but if it be without the dome, it will be weaker.

From the mutual tendency of the parts to the axis, a dome admits of an opening in the centre; but it is not a matter of indifference whether the weight be omitted or not in determining the curve of equilibrium. The reader will, however, easily perceive, that the external covering may have any form that is most consistent with the other parts of the building, as these calculations refer to the supporting frame only. The strongest forms are generally the most beautiful, but the consideration of beauty of form does not come within the plan of this work.

* Encyclopædia Britannica.

*General Observations on Designing, Framing, &c.*

67. The principal questions relative to the action of forces on single beams, and on systems of framing, have now been considered; and it only remains to make a few remarks on the best method of applying those principles so as to form a perfect design.

In the first place, the artist must remember, "that the strength of a piece of framing, whatever may be the design, can never exceed that of its weakest parts; and that partial strength produces general weakness*."

Therefore, let the fixed conditions, or those objects which cannot be altered, be well considered; and as far as it can be done, let them be drawn correctly to a scale; showing the curves of equilibrium, the points where the forces act, and every other particular condition. Also, it must be considered whether the forces are to act constantly on the same parts, or to be subject to changes; and the nature and extent of these changes should be exhibited.

2ndly. The nature of the sustaining points should be carefully examined, whether they be capable of resisting a force acting obliquely against them or not; and the framing must be disposed accordingly.

Then a design may be sketched in, of such a nature as shall appear best adapted to attain the objects in view; the strength of the parts being fixed by the rules in the next Section.

Nothing will assist the artist more in forming a good design, than just conceptions of the objects to be attained; and nothing will render those objects more familiar to his mind than drawing them.

* Seppings' Philosophical Transactions.

# SECTION II.

## OF THE RESISTANCE OF TIMBER, OR THE STABILITY OF RESISTANCE.

68. To know the resistance which a piece of timber offers to any force tending to change its form, is one of the most important species of knowledge that a carpenter has to acquire; and to be able to judge of the degree of resistance from observation only, even in common cases, requires nothing less than the practice of a life devoted wholly to carpentry.

Besides, it is a species of knowledge that is confined to the person who has obtained it, and dies with him. It is a feeling of fitness that cannot be communicated, nor yet described; nevertheless it is a feeling that every thinking practical man is sensible he possesses. I am far from having a wish to banish the nice observation that gives birth to this feeling; because it is more desirable that it should be encouraged than suppressed: but there are cases where it fails; that is, when the magnitude of the object is beyond the range of ordinary practice; and where new combinations are attempted. In such cases the laws of the resistance of solids should be referred to, even by the expert practical man; and he will be better able to judge of their correctness if he finds them, in common cases, to give results that agree with those he has drawn from practice.

But there are many, besides practical carpenters, that ought to know something of the principles of building, and who have not an opportunity of becoming acquainted with those principles through practice; to such persons the rules and experiments detailed in this work will be found extremely useful.

In order to be able to determine the dimensions or scantling of a piece of timber, that shall be capable of sustaining a given weight or pressure, the laws that regulate its resistance should be considered; and to accomplish this in a manner that is likely to be useful, we must consider what effect is produced when a piece of timber is overloaded. This effect, in general, is nothing more than a certain degree of flexure, or bending, as it seldom happens that timbers are absolutely broken; and, generally, a small degree of bending renders a beam unfit for its intended purpose.

Much has been said on the irregular nature of timber, and that it is impossible to make rules or tables for scantlings on that account; but it must be observed, that these remarks apply only to rules for the strength of timber to resist breaking; and even in that case timber is not so irregular as is generally imagined. The difference in good timber is still less perceptible when the bending only is considered, and the laws of flexure are founded on experiments of the most unexceptionable nature. It has been shown in the preceding section (Section I. art. 18) that a change in the position of the resisting parts

brings new forces into action, which is the cause of the irregularity observed by Buffon in his experiments *; but in a piece of carpentry these changes must never be so great as to produce a sensible effect; therefore it would be an useless refinement to attempt to form rules that would embrace all the circumstances these changes produce; besides, it would render them too complicated to be useful.

In all cases timbers that are exposed to considerable strains ought to be of a good quality; therefore the data should be drawn from experiments on good timber, and not from inferior specimens. For if inferior specimens were made the basis of calculation, at what point of inferiority should we begin? and how should it be described so as to enable us to compare it with any other timber? But when it is known what a piece of good timber will do, it will be easy to compare its description with that to be used. Good timber is that which is perfectly sound, straight grained, free from large knots or other defects, particularly near the strained points, and seasoned. Specimens of this kind I have marked *medium* in the tables of experiments. In Section X. the reader will find further information respecting the nature and qualities of different kinds of timber.

But the qualities even of good timber vary in some degree according to the nature of the earth it is grown upon, and the dryness and exposure of the situation where it was grown. The age of trees at the time of cutting, the natural defects, such as knots, shakes, &c. also the mode of seasoning, or the comparative dryness, is the cause of some difference in the strength and stiffness of timber: all these things considered, it is impossible to calculate correctly its strength and stiffness. But, fortunately, that precision which is so essential to the philosopher, is not absolutely necessary to the architect and engineer. They content themselves with approximations that are simple, and more easily obtained; and, provided that the limits which cannot be passed with safety be pointed out, these approximations are sufficient to direct their practice.

### DEFINITIONS, AND GENERAL PRINCIPLES.

69. The laws of the resistance of materials depend on the manner in which the pieces are strained, and may be divided into three kinds.

First, When the force tends to pull the piece asunder in direction of its length, or the *resistance to tension*.

Secondly, When the force tends to break the piece across, or the *resistance to cross strains*.

Thirdly, When the force tends to compress the body in the direction of its length, or the *resistance to compression*.

* Mémoires de l'Académie des Sciences, 1741, p. 328—332.

70. *Stiffness* is that property of bodies by which they resist flexure or bending. *Strength* is that by which they resist fracture or breaking. This distinction must be carefully attended to, because the laws of strength and stiffness are not the same. For instance, the stiffness of a cylinder, exposed to a cross strain, increases as the fourth power of the diameter, but the strength increases only as the cube of the diameter. If the diameter of a cylinder be doubled, its stiffness will be sixteen times as great, but its strength will only be increased eight times.

In carpentry the comparative stiffness is of much greater importance than the comparative strength, as timbers are seldom exposed to strains that break them.

71. All bodies may be extended or compressed; and the extension or compression is directly as the force producing it: that is, if a force of 100 pounds produce an extension of one-tenth of an inch, 200 pounds will produce an extension of two-tenths of an inch, and so on. It is on the truth of this principle that the greater part of the following inquiry depends; and it has been found by experiment to be perfectly regular to an extent that embraces all useful cases. It has no other proof than "a large experience without a single exception;" but this will be deemed a sufficient one.

### ON THE RESISTANCE TO TENSION.

In conformity to the principle of distinguishing stiffness from strength, this subject divides itself into two parts. And, first,

#### *Of the Stiffness of Bodies to resist a Strain in the Direction of their Length.*

72. It is apparently the most simple case of extension when a piece is pulled in the direction of its length; but in reality it is the most complicated, or at least the most difficult to account for in a theoretical point of view. According to some experiments made on iron*, the extension appears to be as the square of the length. But as these experiments are not sufficient to establish the law of variation, I shall follow the usual train of reasoning.

When a beam is strained in the direction of its length, the quantity it extends is directly proportional to the number of parts extended, or to the length of the piece; and also as the weight.

The extension will be inversely proportional to the area of the section, or inversely as the breadth and thickness.

Let L be the length in feet, W the weight in pounds, B the breadth in inches, and T the thickness in inches. Then $\frac{L \times W}{B \times T}$ is as the extension. Or when the extension is given $L \times W : B \times T$. Also $L \times W \times a = B \times T$†. (1.)

* Barlow's Essay on the Strength of Timber, &c. p. 228—230.

† Emerson's Geometry, p. 216. prop. 9.

Where $a$ is a quantity derived from experiment, and is found from the equation $a = \frac{B \times T}{L \times W}$.

The equation (1.) applies to king-posts, queen-posts, spears of pumps, &c.

73. We have no experiments that have been made with the intention of obtaining data for this case; but while the elasticity of the timber remains perfect the following values of $a$ are deduced from experiments on the resistance to transverse or cross strains.

TABLE I.—*Of Constant Numbers for the Resistance to Tension.*

| | | |
|---|---|---|
| British timber | Oak | $a = {\cdot}00013$ |
| | Larch | $a = {\cdot}00014$ |
| | Scotch fir | $a = {\cdot}00015$ |
| | Ash | $a = {\cdot}0001$ |
| Foreign timber | Memel or Riga yellow fir | $a = {\cdot}00016$ |
| | Norway yellow fir | $a = {\cdot}00011$ |
| | American pine | $a = {\cdot}00024$ |
| | White spruce | $a = {\cdot}00013$ |
| | Oak from Riga | $a = {\cdot}00012$ |
| | Oak from America | $a = {\cdot}000125$ |

74. RULE I. Multiply the weight in pounds to be suspended by the length of the suspending piece in feet; this product multiplied by the decimal corresponding to the kind of wood will give the area of the piece in inches. The extension of beams strained in the direction of their length being very small, it may be considered unnecessary to introduce the effect of the length: I have done so more on account of the weight of the piece, and risk of failure in long pieces, than on account of the actual extension.

### *Of the Strength of a Beam to resist a Strain in the Direction of the Length.*

75. The strength to resist a weight that will produce fracture is as the area of the section. Consequently,

RULE II. Multiply the area of the section in inches, by the weight that will tear asunder a bar an inch square of the same kind of wood, and the product will be the weight in pounds the piece will just support, but only one-fourth of this should be the greatest constant load any piece should sustain. The same rule applies to iron, and to the cohesion of timber when it is pulled asunder at right angles to the direction of the fibres.

The following table contains the results of the chief experiments that have been made

on the direct strength. Emerson's numbers do not give the full strength; and Anderson's are much below the true value of the cohesive force; most likely he has intended those numbers to represent the load that a square inch would bear with safety.

76. TABLE II.—*Cohesive Force of a Square Inch of different Woods**.

| Kind of wood. | Cohesion of a square inch in pounds. | Experimentalist. | Kind of wood. | Cohesion of a square inch in pounds. | Experimentalist. |
|---|---|---|---|---|---|
| Oak .......... | 17,300 | Muschenbroek. | Elm .......... | 13,489 | Muschenbroek. |
| Ditto ......... | 13,950 | Rondelet. | Ditto ......... | 6,070 | Emerson. |
| Ditto, dry English from / to | 12,000 / 8,889 | Barlow. | Ditto ......... | 4,455 | Anderson. |
| Ditto ......... | 7,850 | Emerson. | Acacia ........ | 20,582 | Muschenbroek. |
| Ditto ......... | 6,114 | Anderson. | Mahogany .... | 8,000 | Barlow. |
| Beech ........ | 17,709 | Muschenbroek. | Walnut ....... | 8,130 | Muschenbroek. |
| Ditto ......... | 11,500 | Barlow. | Ditto ......... | 5,360 | Emerson. |
| Ditto ......... | 6,300 | Anderson. | Teak ......... | 15,000 | Barlow. |
| Ditto ......... | 6,070 | Emerson. | Poplar .. from / to | 6,641 / 4,596 | Muschenbroek. |
| Alder ......... | 14,186 | Muschenbroek. | Fir ..... from / to | 13,448 / 11,000 | Barlow. |
| Ditto ......... | 5,094 | Anderson. | Ditto ......... | 8,506 | Muschenbroek. |
| Ditto ......... | 4,290 | Emerson. | Ditto ......... | 5,000 | Emerson. |
| Sycamore ..... | 5,000 | Emerson. | Pitch pine ..... | 7,818 | Muschenbroek. |
| Chesnut, Spanish | 13,300 | Rondelet. | Norway pine ... | 7,287 | Rondelet. |
| Ash .... from / to | 17,850 / 15,784 | Barlow. | Larch ......... | 10,220 | Rondelet. |
| Ditto ......... | 12,000 | Muschenbroek. | Cedar ......... | 4,973 | Muschenbroek. |
| Ditto ......... | 6,300 | Anderson. | | | |
| Ditto ......... | 6,070 | Emerson. | | | |

77. TABLE III.—*Cohesion of a Square Inch pulled asunder in a Direction perpendicular to the Length of the Fibres.*

| Kind of wood. | Cohesion of a square inch perpendicular to fibres, in pounds. | Experimentalist. |
|---|---|---|
| Oak ....... | 2316 | By my trial. |
| Poplar ..... | 1782 | Idem. |
| Larch ..... | from 970 to 1700 | Idem. |

* In this table all the experiments were made by pulling specimens of the woods asunder in the direction of their length. Muschenbroek's are from his Intro. ad Phil. Nat. tom. i. p. 414, 415; Barlow's, from his Essay on the Strength of Timber, p. 76—78; Emerson's and Anderson's are from the Edinburgh Encyclopædia, art. Carpentry; and Rondelet's from vol. iv. of his L'Art de Bâtir.

Emerson states, that tough wood, such as elm and ash, is from 7 to 8, and even 10 times weaker across the grain than when strained in the direction of the fibres; and that straight grained woods, such as fir, are from 16 to 20 times weaker than in the length of the fibres.

78. The cohesive force of different kinds of iron is shown in the following table, which will be of service in finding the dimensions of straps, &c.

TABLE IV.—*Cohesive Force of Iron.*

| Kind of iron. | Cohesion of a square inch in pounds. | Experimentalist. | Kind of iron. | Cohesion of a square inch in pounds. | Experimentalist. |
|---|---|---|---|---|---|
| Iron wire .... | 113,077 | Sickengen. | English iron .. | 61,600 | Telford. |
| Ditto ....... | 93,964 | Telford. | Ditto ....... | 55,772 | Rennie. |
| Swedish iron . | 78,850 | Muschenbroek. | Welsh iron ... | 64,960 | Telford. |
| Ditto ....... | 72,064 | Rennie. | Ditto ....... | 55,776 | Brown. |
| Ditto ....... | 64,960 | Telford. | French iron .. | 61,041 | Perronet. |
| Ditto ....... | 53,244 | Brown. | Russian iron .. | 59,472 | Brown. |
| German iron . | 69,133 | Muschenbroek. | Cast iron .... | 68,295 | Muschenbroek. |
| English iron from | 66,000 | Rumford. | Ditto ....... | 19,488 | Rennie. |
| to | 55,000 | | Ditto, Welsh . | 16,255 | Brown. |

The load upon a square inch, either of wood or iron, should not exceed one-fourth of the weight that would produce fracture.

## ON THE RESISTANCE TO CROSS STRAINS.

### *Of the Stiffness of Beams to resist Cross Strains.*

79. When a weight is laid upon the middle of a piece of timber that is supported only at the ends, it always bends more or less. When the weight bends the piece in a very small degree, the piece is said to be stiff; when the bending is considerable, it is called flexible.

The stiffness of beams is proportional to the space they are bent through by a given weight, when the lengths are the same; but that two pieces of different lengths may be equally stiff, the deflexion, or bending, should be proportional to their lengths. For a deflexion of one-fourth of an inch in a joist 20 feet long, would not be attended with any bad effect; but if a joist 4 feet long were to bend one-fourth of an inch, it would be totally unfit for the purpose. Hence the rules given by mathematical writers

for determining the stiffness of beams are not adapted to the carpenter's purpose; yet they are perfectly correct on the principle of making the deflexion always the same, whatever the length may be; and the rules given in this work may be immediately derived from them by making the deflexion proportional to the length, as it ought to be.

### *Of the Stiffness of Beams supported at both Ends.*

80. When a beam is supported at the ends only, in a horizontal position, and the weight rests upon the middle between the points of support, the laws of deflexion may be determined as follows:

The extension of any part of the beam is directly as the force which produces it; and it is known by experiment, that the deflexion is as the weight; therefore, the deflexion is as the extension.

Now the effect of a force to produce extension is as the leverage it acts with, and as the force itself; but the leverage is proportional to the length of the beam; therefore, the extension is as the length and weight directly; and inversely as the breadth, and square of the depth, as is shown by writers on the strength of materials.

Also, the extension will be directly as the number of parts extended, that is, directly as the length; and as the quantity of angular motion, which will be as the length directly, and depth inversely. Uniting these proportions, we find the extension will be as the weight, and cube of the length, directly, and as the breadth, and cube of the depth, inversely; consequently, the deflexion will be in the same proportion, that is, making L=the length of bearing in feet, W=the weight in pounds, B=the breadth in inches, and D=the depth in inches, $\frac{L^3 \times W}{B \times D^3}$ is as the deflexion*.

But in order that a beam may be equally stiff, according to the definition of stiffness given in a preceding article (art. 79,) the deflexion should be inversely as the length; consequently, the weight that a beam will sustain, so that the deflexion shall be proportional to the length, is as the breadth and cube of the depth directly, and as the square of the length inversely; or $\frac{B \times D^3}{a \times L^2} = W$. (2.)

And when the weight is given $\frac{W \times L^2 \times a}{B} = D^3$. Where $a$ is a constant quantity to be determined from experiment.

81. When the beam is placed in an inclined position, and the angle which it makes with the horizon is denoted by $c$; then, $\frac{a \times W \times L^2 \times \cos. c}{B} = D^3$. (3.)

* The same result is obtained by a different process by Dr. Thomas Young, Nat. Phil. vol. ii. art. 332.

82. The quantity of timber being the same, a beam will be stronger in proportion as its depth is greater; but there is a certain proportion between the depth and breadth, which, if it be exceeded, the beam will be liable to overturn, and break sideways. To avoid which, the breadth should never be less than that given by the following rule, unless the beam be held in its position by some other means.

RULE III. Divide the length in feet by the square root of the depth in inches, and the quotient multiplied by the decimal 0·6 will give the least breadth that should be given to the beam.

When the depth is not determined by other circumstances, the nearer its form approaches to that determined by the rule, the stronger it will be; and, from the same rule, another is easily obtained which will show the advantage of making the beams thin and deep.

83. To find the strongest form for a beam, so as to use only a given quantity of timber.

RULE IV. Multiply the length in feet by the decimal 0·6, and divide the given area in inches by the product; and the square of the quotient will give the depth in inches.

*Example.* If the bearing be 20 feet, and the given area of section be 48 inches; then, $\frac{48}{0{\cdot}6\times 20}=\frac{48}{12}=4$, and the square of 4 is 16 inches, the depth required; and the breadth will be 3 inches. A beam 16 inches by 3 would bear more than twice as much as a square beam of the same area of section; which shows how important it is to make beams deep and thin. In many old buildings, and even in new ones, in country places, the very reverse of this has been practised; the principal beams being oftener laid on the broad side than the narrower one.

84. The stiffest beam that can be cut out of a round tree, is that of which the breadth is to the depth as 1 is to the square root of 3*, or as 1 is to 1·732, nearly; or as ·58 is to 1; and, as this is in general a good proportion for beams that have to sustain a considerable load, and where it would be impossible to get them deeper on account of the size of the tree, we may substitute this value of the depth in the equations (2.) and (3.)

which then become $L\times\left(\frac{a\times W}{\cdot 58}\right)^{\frac{1}{2}}=D^2$. (4.)

And for inclined beams, $L\times\left(\frac{a\times W\times \cos.\, c}{\cdot 58}\right)^{\frac{1}{2}}=D^2$. (5.)

* Young's Nat. Phil. vol. ii. art. 338.

*Experimental Data.*

85. Before these rules can be applied the value of $a$ must be got from experiments.

*Experiments on Oak.*

Duhamel made some experiments on oak, where the scantlings were as large as they are generally used in buildings; and as the results of experiments on large pieces will be most highly valued by the generality of readers, I shall here describe as much of them as is applicable to the present purpose.

A piece of oak 9·6 inches deep and 10·66 inches in breadth, was placed upon two supports 24·5 feet apart, and a weight of 8198 pounds was suspended to the middle, which bent it in the middle 3·73 inches. The piece broke with 9613 pounds, but it was found to have been faulty. The value of $a$ for a deflexion of one-fortieth of an inch per foot in length is 0·0114.

Another piece of oak, which was very sound and straight grained, the depth 12·2 inches, the breadth 10·66 inches, and the bearing 24·5 feet; with a weight of 8198 pounds bent 2·65 inches. Whence for a deflexion of one-fortieth of an inch per foot in length, $a=0·0157$. The piece broke with a weight equivalent to 19,666 pounds applied to the middle.

A third piece of oak, that was sound and straight grained, was tried; the depth was 13·83 inches, the breadth 12·8 inches, and the length 24·5 feet; and with a weight of 8198 pounds it bent an inch in the middle*. Therefore for a deflexion of one-fortieth of an inch per foot $a=0·011$.

These are the only experiments on oak made on a large scale where the deflexion has been measured while the elasticity of the pieces remained perfect, excepting Girard's experiments. The following table contains the results of my own experiments, together with a selection from other writers.

* Mémoires de l'Académie des Sciences, Paris, 1768, p. 535—537.

86. TABLE V.—*Experiments on the Stiffness of Oak.*

| Kind of oak. | Specific gravity. | Length in feet. | Breadth in inches. | Depth in inches. | Deflexion in inches. | Weight producing the deflexion in pounds. | Values of $a$. | Authorities. |
|---|---|---|---|---|---|---|---|---|
| Old ship timber ... | ·872 | 2·5 | 1 | 1 | 0·5 | 127 | ·00998 | By my trial. |
| Oak from young tree, King's Langley, Herts. | ·863 | 2 | 1 | 1 | 0·5 | 237 | ·0105 | Idem. |
| Oak from Beaulieu, Hants. ... | ·616 | 2·5 | 1 | 1 | 0·5 | 78 | ·0164 | Idem. |
| Ditto, another specimen .... | ·736 | 2·5 | 1 | 1 | 0·5 | 65 | ·0197 | Idem. |
| Oak from old tree . | ·625 | 2 | 1 | 1 | 0·5 | 103 | ·024 | Idem. |
| Oak from Riga .... | ·688 | 2 | 1 | 1 | 0·5 | 233 | ·0107 | Idem. |
| English oak ...... | ·960 | 7 | 2 | 2 | 1·275 | 200 | ·0119 | Barlow. |
| Canadian oak ..... | ·867 | 7 | 2 | 2 | 1·07 | 225 | ·009 | Idem. |
| Dantzic oak ...... | ·787 | 7 | 2 | 2 | 1·26 | 200 | ·0105 | Idem. |
| Adriatic oak ...... | ·948 | 7 | 2 | 2 | 1·55 | 150 | ·0193 | Idem. |
| English oak ...... | ·748 | 2·5 | 1 | 1 | 0·5 | 137 | ·00934 | Ebbels. |
| Ditto, green ...... | ·763 | 2·5 | 1 | 1 | 0·5 | 96 | ·0133 | Idem. |
| Dantzic oak, seasoned ........ | ·755 | 2·5 | 1 | 1 | 0·5 | 148 | ·0087 | By my trial. |
| Oak, seasoned .... | | 12·8 | 3·19 | 3·19 | 1·06<br>4·25 | 268<br>803 | ·008<br>·0105 | Aubry. |
| Oak, green ....... | | 6·87 | 5·3 | 5·3 | ·433 | 7587 | ·005 | Buffon. |
| Oak, green ....... | | 23·58 | 5·3 | 5·3 | 2·7 | 706 | ·0095 | Idem. |
| Oak ............ | | 8·52 | 5·06 | 6·22 | 0·709 | 4146 | ·0133 | Girard. |
| Oak (bois du brin*) | | 16·86 | 10·66 | 11·73 | 0·67 | 4559 | ·0213 | Idem. |
| Oak (quercus sessiliflora) ...... | | 2 | 1 | 1 | 0·35 | 149 | ·0117 | By my trial. |
| Oak (quercus robur†) ........ | | 2 | 1 | 1 | 0·35 | 167 | ·0104 | Idem. |

* "Bois du brin," timber the whole size of the tree, excepting that which was taken off to render it square.

† See Section X. art. 376, where the characters of these species are described.

87. TABLE VI.—*Experiments on the Stiffness of Fir.*

| Kind of fir. | Specific gravity. | Length in feet. | Breadth in inches. | Depth in inches. | Deflexion in inches. | Weight producing the deflexion in pounds. | Values of $a$. | Authorities. |
|---|---|---|---|---|---|---|---|---|
| Riga yellow fir, medium | | 18 | 2 | 7 | 0·25 | 103 | ·0115 | By my trial. |
| Yellow fir, from Long Sound, Norway | ·6398 | 2 | 1 | 1 | 0·5 | 261 | ·00957 | Idem. |
| Yellow fir, Riga | ·480 | 2·5 | 1 | 1 | 0·5 | 123 | ·0102 | Idem. |
| | ·464 | 2·5 | 1 | 1 | 0·5 | 116 | ·011 | Ebbels. |
| Ditto, Memel, medium | ·553 | 2·5 | 1 | 1 | 0·5 | 143 | ·0089 | By my trial. |
| | ·544 | 2·5 | 1 | 1 | 0·5 | 145 | ·0088 | |
| American pine, supposed to be the Weymouth pine | ·460 | 2 | 1 | 1 | 0·5 | 237 | ·0105 | Idem. |
| | ·407 | 3 | 1 | 1 | 0·5 | 69 | ·0112 | |
| White spruce, Christiana | ·512 | 2 | 1 | 1 | 0·5 | 261 | ·00957 | Idem. |
| White spruce, Quebec | ·4650 | 2 | 1 | 1 | 0·5 | 180 | ·0138 | Idem. |
| Pitch pine | ·712 | 7 | 2 | 2 | 1·33 | 150 | ·0166 | Barlow. |
| New England fir | ·560 | 7 | 2 | 2 | ·970 | 150 | ·0121 | Idem. |
| Riga fir | ·765 | 7 | 2 | 2 | ·912 | 150 | ·01137 | Idem. |
| Scotch fir, Mar Forest | ·715 | 7 | 2 | 2 | 1·560 | 125 | ·0233 | Idem. |
| Larch, Blair, Scotland, dry | ·622 | 2·5 | 1 | 1 | 0·5 | 93 | ·0137 | By my trial. |
| Ditto, seasoned, medium | ·644 | 2·5 | 1 | 1 | 0·5 | 101 | ·0126 | Idem. |
| | ·554 | 2·5 | 1 | 1 | 0·5 | 112 | ·0111 | Ebbels. |
| Ditto, very young wood | ·396 | 2·5 | 1 | 1 | 0.5 | 45 | ·0284 | By my trial. |
| Scotch fir* | ·529 | 2·5 | 1 | 1 | 0·5 | 89 | ·01437 | Idem. |
| Spruce fir, British | ·55 5 | 2·5 | 1 | 1 | 0·5 | 03 | ·0124 | Ebbels. |
| Fir (bois du brin) | | 21·3 | 10·48 | 10·48 | 1·02 | 4389 | ·0115 | Girard. |
| Fir (bois du brin) | | 10·65 | 10·48 | 10·48 | 0·2245 | 4122 | ·022 | Idem. |

* The tree from which this specimen was taken was grown in Buckinghamshire.

88. TABLE VII.—*Experiments on the Stiffness of various Woods.*

| Kind of wood. | Specific gravity. | Length in feet. | Breadth in feet. | Depth in inches. | Deflexion in inches. | Weight producing the deflexion in pounds. | Values of $a$. | Authorities. |
|---|---|---|---|---|---|---|---|---|
| Ash from young tree, white coloured | ·811 | 2·5 | 1 | 1 | 0·5 | 141 | ·009 | By my trial. |
| Ash from old tree, red coloured | ·753 | 2·5 | 1 | 1 | 0·5 | 113 | ·0113 | Idem. |
| Ash, medium quality | ·690 | 2·5 | 1 | 1 | 0·5 | 78·5 | ·0163 | Ebbels. |
| Ash | ·760 | 7 | 2 | 2 | 1·27 | 225 | ·0105 | Barlow. |
| Beech | ·688 | 7 | 2 | 2 | 1·025 | 150 | ·01277 | Idem. |
| Teak | ·744 | 7 | 2 | 2 | 1·276 | 300 | ·0076 | Idem. |
| Elm | ·540 | 7 | 2 | 2 | 1·42 | 125 | ·0212 | Idem. |
| Elm | ·544 | 2·5 | 1 | 1 | 0·5 | 99·5 | ·0128 | Ebbels. |
| Cedar of Lebanon | ·486 | 2·5 | 1 | 1 | 0·5 | 36 | ·0355 | By my trial. |
| Maple, common | ·625 | 2·5 | 1 | 1 | 0·5 | 65 | ·0197 | Idem. |
| Abele | ·511 | 2·5 | 1 | 1 | 0·5 | 84 | ·0152 | Idem. |
| Willow | ·405 | 2·5 | 1 | 1 | 0·5 | 41 | ·031 | Idem. |
| Horse chesnut | ·4838 | 2·5 | 1 | 1 | 0·5 | 79 | ·0162 | Idem. |
| Lime tree | ·483 | 2·5 | 1 | 1 | 0·5 | 84 | ·0152 | Idem. |
| Walnut, green | ·920 | 2·5 | 1 | 1 | 0·5 | 62 | ·020 | Ebbels. |
| Spanish chesnut, green | ·895 | 2·5 | 1 | 1 | 0·5 | 68·5 | ·0187 | Idem. |
| Acacia, green | ·820 | 2·5 | 1 | 1 | 0·5 | 125 | ·0102 | Idem. |
| Plane, dry | ·648 | 2·5 | 1 | 1 | 0·5 | 99·5 | ·0128 | Idem. |
| Alder, ditto | ·555 | 2·5 | 1 | 1 | 0·5 | 80·5 | ·0159 | Idem. |
| Birch, ditto | ·720 | 2·5 | 1 | 1 | 0·5 | 90·5 | ·0141 | Idem. |
| Beech, ditto | ·690 | 2·5 | 1 | 1 | 0·5 | 97·5 | ·0131 | Idem. |
| Wych elm, green | ·763 | 2·5 | 1 | 1 | 0·5 | 92 | ·014 | Idem. |
| Lombardy poplar, dry | ·374 | 2·5 | 1 | 1 | 0·5 | 56·5 | ·0224 | Idem. |
| Honduras mahogany | ·560 | 2·5 | 1 | 1 | 0·5 | 118 | ·0109 | By my trial. |
| Spanish, ditto | ·853 | 2·5 | 1 | 1 | 0·5 | 93 | ·0137 | Idem. |
| Sycamore | ·590 | 2·5 | 1 | 1 | 0·5 | 76 | ·0168 | Ebbels. |
| Pear tree, green | ·792 | 2·5 | 1 | 1 | 0·5 | 59·5 | ·0215 | Idem. |
| Cherry tree, green | ·690 | 2·5 | 1 | 1 | 0·5 | 92·5 | ·0138 | Idem. |

89. The constant number $a$ is calculated on the supposition that the deflexion is equal to one-fortieth of an inch for each foot in length: that is, when the length is one foot the weight will produce a deflexion of one-fortieth of an inch; when the length is 20

feet, the deflexion will be twenty-fortieths, or half an inch, and so on. Therefore, the reader must consider when he intends to calculate the scantling of a beam, what degree of deflexion the beam may take without injury to the work. When the deflexion is required to be less than I have assumed, then multiply the constant number $a$ by some number that will reduce the deflexion to the proposed degree: for instance, if the deflexion should be only half of one-fortieth, multiply $a$ by 2; if one-third of one-fortieth, multiply $a$ by 3, &c. Also, if the deflexion may be greater than one-fortieth per foot, divide $a$ by 2, 3, or any number of times that the proposed deflexion may exceed one-fortieth of an inch per foot.

By means of the above experiments, and the equations (2.) and (3.) the scantling of a piece of timber may easily be determined: for the use of those who do not understand algebraic expressions the rules are given at length below, with examples.

### *Rules for the Stiffness of Beams.*

90. To find the scantling of a piece of timber that will sustain a given weight when supported at the ends in a horizontal position, the bearing being given.

#### *Case 1.—When the Breadth is given.*

RULE V. Multiply the square of the length in feet by the weight in pounds, and this product by the value of $a$ opposite the kind of wood in the preceding tables. (Table V. VI. or VII.) Divide the product by the breadth in inches, and the cube root of the quotient will be the depth required in inches.

*Example.* A beam of Norway fir is wanted for a 24 feet bearing to support 900 pounds, and the breadth to be 6 inches; required the depth? Here $\frac{24 \times 24 \times 900 \times \cdot 00957}{6} = 827$; and the cube root of 827 is 9·38, the depth required in inches.

#### *Case 2.—When the Depth is given.*

91. RULE VI. Multiply the square of the length in feet by the weight in pounds, and multiply this product by the value of $a$ opposite the name of the kind of wood in Table V. VI. or VII. Divide the last product by the cube of the depth in inches, and the quotient will be the breadth in inches required.

*Example.* The space for a beam of oak does not allow it to be deeper than 12 inches;

to find the breadth so that it may support a weight of 4000 pounds, the bearing being 16 feet. Here $\frac{16\times 16\times 4000\times \cdot 0164}{12\times 12\times 12}=9\frac{1}{4}$ inches nearly, the breadth required.

92. But, generally, neither the breadth nor depth is given: in this case it will be best to fix on some proportion which the breadth should have to the depth; for instance, suppose it to be convenient to make the breadth to the depth as 0·6 is to 1, then the rule would become as follows:

RULE VII. Multiply the weight in pounds by the value of *a* opposite the kind of wood in the foregoing tables (Table V. VI. or VII.;) divide the product by 0·6, and extract the square root. Multiply this root by the length in feet, and extract the square root a second time, which will be the depth in inches required. The breadth is equal to the depth multiplied by the decimal 0·6. It is obvious, that any other proportion of the breadth and depth may be obtained by merely changing the decimal 0·6 in the rule.

*Example.* A beam of Riga fir is intended to bear a ton weight in the middle of its length, the bearing is 22 feet; what should be the dimensions of the beam? A ton is 2240 lbs. Here $\frac{2240\times \cdot 011}{\cdot 6}=41\cdot 066$; the square root of 41·066 is 6·4 nearly. Therefore $6\cdot 4\times 22=140\cdot 8$; and the square root of 140·8 is 11·86 inches, the depth required. And $11\cdot 86\times \cdot 6=7\cdot 116=$ the breadth.

93. When the beam is inclined the scantling will be found by the following rule:

RULE VIII. Multiply together the weight in pounds, the cosine of the angle the beam makes with the horizon to a radius of unity, and the constant number *a* for the kind of wood; divide this product by 0·6, and extract the square root of the quotient. Multiply this root by the length in feet, and extract the square root again, which will give the depth in inches.

94. Otherwise, let AB (*fig.* 22, *Plate* II.) be the beam, and BC a vertical line; then AC will be the horizontal distance between the points of support.

RULE IX. Multiply together the weight in pounds, the length of the beam in feet, the horizontal distance between the supports in feet, and the constant number *a* for the kind of wood; divide this product by 0·6, and the fourth root of the quotient will give the depth in inches. According to either rule, the breadth is equal to the depth multiplied by the decimal 0·6.

*Example.* Let the length of the beam be 20 feet, and the horizontal distance between the points of support 16 feet, and the weight to be supported one ton, or 2240 pounds, by a beam of Riga fir. Then $\frac{2240\times 20\times 16\times \cdot 011}{\cdot 6}=13240$; the fourth root of 13240 is $10\frac{3}{4}$ nearly, and $10\frac{3}{4}\times \cdot 6=6\frac{1}{2}$ nearly; therefore the beam should be $10\frac{3}{4}$ inches by $6\frac{1}{2}$ inches.

*When the Beam is fixed at both Ends and loaded in the Middle.*

95. The strain upon a beam fixed at both ends has excited much attention, in consequence of a supposed difference between the result of theory and experiments. If it had been possible to fix a beam so that it should not have suffered extension beyond the point of fixing, the demonstrations of Emerson* and Professor Robison† would have been perfectly correct; but it is evident, that the beam will be extended beyond the point of support, and the quantity of extension must depend on the mode of fixing. According to the experiments of Belidor, the strength of a beam fixed at both ends is to the strength of a beam only supported at the ends as 3 is to 2‡. M. Parent obtained nearly the same result. The stiffness will be nearly in the same proportion.

But we cannot in practice fix the ends of a beam into a wall without endangering its stability, therefore the determination of the stiffness of beams to suit such a case is not an object of much importance.

When, however, a long beam AB, is laid over several points of support, as in *fig.* 33, *Plate* III. a case of very common occurrence in building, the strength of the intermediate parts is nearly doubled, or twice as much as when the beams are cut into short lengths. Hence the carpenter will see the importance of using bridging and ceiling joists, and purlins, and rafters, in considerable lengths, so that a joist may extend over several binding joists, purlins over several trusses, and a rafter over several purlins; also, by contriving so that the joinings shall not be opposite one another, a floor or roof may be made tolerably equal in strength. Hence, also, we see the importance of notching joists, purlins, and rafters over the supports, instead of framing them between.

*Of the Stiffness of Cylinders supported at both Ends.*

96. When a solid cylinder is supported at both ends. Let D be the diameter of the cylinder; then $W \times L^2 \times \text{constant quantity} = D^4$. (6.)

Now it is shown by Dr. Young, that the stiffness of a cylinder is to that of its circumscribing rectangular prism, as three times the bulk of the cylinder is to four times the bulk of the prism §; and by equation (2.) the stiffness of the prism is $= \frac{B^4}{a \times L^2}$. Therefore $\frac{3 \times \cdot 7854 \times D^4}{4a \times L^2} = W$, or $17a \times L^2 \times W = D^4$. (7.)

From want of proper experiments this method of obtaining the stiffness of cylinders

* Emerson's Algebra, prob. 182, p. 464.

† Art. Carpentry, Supplement to the Encyclopædia Britannica.

‡ Sciences des Ingenieurs, liv. iv. chap. 3.

§ Natural Philosophy, vol. ii. art. 339, B.

has been resorted to; as the only experiments on cylinders, where the first deflexions are given, are those of Duhamel, which were made on very small specimens*.

97. To find the stiffness of a solid cylinder, or rather the dimensions, so that it may be capable of supporting a given weight; and the deflexion not exceed one-fortieth of an inch for each foot in length.

RULE X. Multiply the value of $a$ for the kind of wood from the tables, art. 86, 87, or 88, by 1·7, and multiply this product by the weight in pounds. Then multiply the square root of the last product by the length in feet, and the square root of the quotient will be the diameter of the cylinder in inches.

*Example.* A solid cylinder of elm is intended to support 10 hundred weight (or 1120 pounds,) the length of bearing 10 feet; required the diameter? The constant number for elm being ·0212, by one of the experiments in Table VII. art. 88.

In this case we have $1{\cdot}7 \times {\cdot}0212 \times 1120 = 40{\cdot}3648$, and the square root of 40·3648 is 6·35, therefore $10 \times 6{\cdot}35 = 63{\cdot}5$; of which the square root is 7·97 inches, the diameter required; or nearly 8 inches.

### *Of the Stiffness of Beams when fixed at both Ends, and the Weight uniformly diffused over the Length.*

98. Where the weight is uniformly diffused over the length of the beam, the deflexion does not increase in the same proportion as when the weight acts at one point. For where the weight is uniformly diffused it increases as the length, and the deflexion will be as the fourth power of the length; consequently, according to the definition of stiffness I have given in art. 79, the stiffness will be as the cube of the length.

The stiffness of a beam uniformly loaded may be derived from the general proportion $BD^3$ is as $L^3W$.

This proportion applies to the case of the rafters, and purlins of a roof, to ceiling joists, and binding joists that support ceilings only, but it does not apply to flooring joists, because their stiffness is measured by the resistance offered to a strain at one point; a floor might seem stiff enough to support a uniform load, and yet shake very much by the weight of a single person moving over it.

99. The above method may be applied in cases where beams are similarly loaded, as in rafters, ceiling joists, &c. but another manner of determining the stiffness may be used in other cases.

For let W be the weight that is uniformly distributed over a beam supported at both ends; then the deflexion produced by this weight uniformly distributed would be to the

* Transport du Bois, p. 460.

deflexion produced by the same weight collected in the middle of the length as 5 : 8, or as 0·625 : 1*. Therefore, in the rules in art. 90, 91, 92, and 93, it is only necessary to employ the weight in pounds multiplied by 0·625 instead of the whole weight, and the rest of the operation is the same as in those rules; therefore it will not be necessary to repeat them.

### *Of the Stiffness of Beams supported at one End.*

100. When a beam is fixed at one end, as in *fig.* 34, *Plate* III. the deflexion is much modified by the method of fixing; the deflexion being greater as the distance AC is greater; because the parts between A and C will be extended, and of course increase the deflexion. And as it is impossible to fix a bar so that it will not be extended beyond the point of support, there is much irregularity in the results of experiments on beams fixed in this manner.

The forms of the equations (2.) (3.) (4.) (5.) (6.) and (7.) remain the same, only a different constant quantity must be used, which may be obtained from the following table of experiments.

101. TABLE VIII.—*Experiments on the Stiffness of Beams supported at one End.*

| Kind of wood. | Specific gravity. | Length in feet. | Breadth in inches. | Depth in inches. | Deflexion in inches. | Weight producing the deflexion in pounds. | Values of constant quantity *b*. | Authorities. |
|---|---|---|---|---|---|---|---|---|
| Dantzic oak ......... | ·854 | 4 | 2 | 2 | 2·5 | 112 | ·222 | Beaufoy. |
| English oak ......... | ·922 | 4 | 2 | 2 | 1·176 | 112 | ·105 | Idem. |
| Ditto, another specimen | | 4 | 2 | 2 | 1·5 | 112 | ·1335 | Idem. |
| Riga fir ............. | ·537 | 4 | 2 | 2 | 1·34 | 112 | ·12 | Idem. |
| Pitch pine ........... | | 4 | 2 | 2 | 1·12 | 112 | ·099 | Idem †. |
| Beech .............. | | 3 | 2 | 2 | 3·375 | 221 | ·313 | Barlow. |

102. As beams fixed at one end are not frequently used in the construction of buildings, it will not be necessary to repeat the rules in words at length.

When the beam is fixed in a horizontal position, $\left(L\times\left(\frac{b\times W}{0\cdot 6}\right)^{\frac{1}{2}}\right)^{\frac{1}{2}}=D.$ (8.)

And $0\cdot 6\ D=B$.

* The demonstration is given in the art. Carpentry, Supplement to the Encyclopædia Britannica, p. 626. prop. F; and in Barlow's Essay on the Strength of Timber, p. 117; and also is evident from art. 326 and 330 of Dr. Young's Natural Philosophy, vol. ii.

† In Colonel Beaufoy's experiments the mean result has been taken of the most regular of his experiments, and the deflexion converted into inches. His experiments are published in Thomson's Annals of Philosophy, vol. ix. p. 274.

When the beam is inclined, and $c$ is the angle of inclination, $\left(L \times \left(\frac{b \times \cos.c \times W}{0{\cdot}6}\right)^{\frac{1}{2}}\right)^{\frac{1}{2}}$ $=D$. (9.)

And $0{\cdot}6\,D=B$.

When a solid cylinder is fixed at one end, $\left(L \times (1{\cdot}7 b \times W)^{\frac{1}{2}}\right)^{\frac{1}{2}}=D$. (10.)

Where the value of $b$ may be obtained from the preceding table, and the deflexion is calculated to be one-fortieth of an inch per foot in length.

*When the Weight is uniformly diffused over the Length of Beams fixed at one End.*

103. When the weight W is uniformly diffused over the length of the beam, the deflexion is to the deflexion of a beam loaded in the middle as $\cdot 75 : 2$; or as $\cdot 375 : 1$. Therefore, instead of W in the above equation substitute $\cdot 375$ W, and the scantlings for beams uniformly loaded may be obtained.

*On the Strength of Beams to resist Cross Strains.*

104. As it may sometimes be desirable to know the greatest weight a beam will bear without fracture, the following rules afford the means of obtaining it sufficiently near for practical purposes. The effect of deflexion is neglected because it does not produce any material difference, unless the depth be very small and the length considerable; a case which can rarely happen in the construction of buildings.

*Strength of Beams supported at both Ends.*

It is shown by writers on the strength of materials, that the strength of rectangular beams supported at both ends is directly as the breadth and square of the depth, and inversely as the length*. Therefore $\frac{B \times D^2 \times c}{L}=W$. (11.)

Where $c$ is a constant number to be ascertained by experiment.

105. When a square beam is strained in the direction of its diagonal its strength is less in the proportion of $0{\cdot}7071$ to 1†.

* Emerson's Mechanics, sect. viii. prop. 67; Gregory's Mechanics, vol. i. art. 169 and 170; Young's Natural Philosophy, vol. ii. art. 335.

† Philosophical Magazine, vol. l. p. 418. The proportions given by Dr. Gregory in this case are not correct.

106. The strength of a solid cylinder is as the cube of its diameter*, therefore $\frac{B^3 \times 1{\cdot}7c}{L} = W$. (12.)

The strength of square beams and cylinders being in the same ratio as their stiffness.

A hollow cylinder is both stronger and stiffer than a solid one containing the same quantity of matter; therefore, where it is desirable to combine strength and lightness, cylinders may be made hollow. In timber this is rather too expensive an operation to be often employed, but there are cases where it is useful. The strength of a tube, or hollow cylinder, is to the strength of a solid one as the difference between the fourth powers of exterior and interior diameter of the tube divided by the exterior diameter, is to the cube of the diameter of a solid cylinder: the quantity of matter in each being the same.

107. The strongest beam that can be cut out of a round tree is that of which the depth is to the breadth as the square root of 2 is to 1†; or nearly as 7 is to 5. And the strength of a square beam cut from the same cylinder, or round tree, is to the strength of the strongest beam nearly as 101 is to 110; but the square beam would contain more timber nearly in the ratio of 5 to 4·714.

*Experiments on the Strength of Beams supported at both Ends.*

108. On this kind of strength the experiments are most numerous, and some of the most important are collected in the following table.

* Emerson's Mechanics, sect. viii. prop. 67. cor. 4; Gregory's Mechanics, vol. i. art. 169, cor. 2.

† This was first demonstrated by M. Parent in the Mémoires de l'Académie, Paris, for 1708.

TABLE IX.—*Experiments on the Strength of Woods.*

| Kind of wood. | Specific gravity. | Length in feet. | Breadth in inches. | Depth in inches. | Deflexion at the time of fracture. | Weight that broke the piece in pounds. | Values of the constant $c$ | Authorities. |
|---|---|---|---|---|---|---|---|---|
| Oak, English, young tree | ·863 | 2 | 1 | 1 | 1·87 | 482 | 964 | By my trial. |
| Ditto, old ship timber | ·872 | 2·5 | 1 | 1 | 1·5 | 264 | 660 | Idem. |
| Ditto, from old tree | ·625 | 2 | 1 | 1 | 1·38 | 218 | 436 | Idem. |
| Ditto, medium quality | ·748 | 2·5 | 1 | 1 | | 284 | 710 | Ebbels. |
| Ditto, green | ·763 | 2·5 | 1 | 1 | | 219 | 547 | Idem. |
| Ditto, from Riga | ·688 | 2 | 1 | 1 | 1·25 | 357 | 714 | By my trial. |
| Ditto, green | 1·063 | 11·75 | 8·5 | 8·5 | 3·2 | 25812 | 595 | Buffon. |
| Beech, medium quality | ·690 | 2·5 | 1 | 1 | | 271 | 677 | Ebbels. |
| Alder | ·555 | 2·5 | 1 | 1 | | 212 | 530 | Idem. |
| Plane tree | ·648 | 2·5 | 1 | 1 | | 243 | 607 | Idem. |
| Sycamore | ·590 | 2·5 | 1 | 1 | | 214 | 535 | Idem. |
| Chesnut, green | ·875 | 2·5 | 1 | 1 | | 180 | 450 | Idem. |
| Ash, from young tree | ·811 | 2·5 | 1 | 1 | 2·5 | 324 | 810 | By my trial. |
| Ditto, medium quality | ·690 | 2·5 | 1 | 1 | | 254 | 635 | Ebbels. |
| Ash | ·753 | 2·5 | 1 | 1 | 2·38 | 314 | 785 | By my trial. |
| Elm, common | ·544 | 2·5 | 1 | 1 | | 216 | 540 | Ebbels. |
| Ditto, wych, green | ·763 | 2·5 | 1 | 1 | | 192 | 480 | Idem. |
| Acacia, green | ·820 | 2·5 | 1 | 1 | | 249 | 622 | Idem. |
| Mahogany, Spanish, seasoned | ·852 | 2·5 | 1 | 1 | | 170 | 425 | By my trial. |
| Ditto, Honduras, seasoned | ·560 | 2·5 | 1 | 1 | | 255 | 637 | Idem. |
| Walnut, green | ·920 | 2·5 | 1 | 1 | | 195 | 487 | Ebbels. |
| Poplar, Lombardy | ·374 | 2·5 | 1 | 1 | | 131 | 327 | Idem. |
| Ditto, abele | ·511 | 2·5 | 1 | 1 | 1·5 | 228 | 570 | By my trial. |
| Teak | ·744 | 7 | 2 | 2 | 4·00 | 820 | 717 | Barlow. |
| Willow | ·405 | 2·5 | 1 | 1 | 3 | 146 | 365 | By my trial. |
| Birch | ·720 | 2·5 | 1 | 1 | | 207 | 517 | Ebbels. |
| Cedar of Libanus, dry | ·486 | 2·5 | 1 | 1 | 2·75 | 165 | 412 | By my trial. |
| Riga fir | ·480 | 2·5 | 1 | 1 | 1·3 | 212 | 530 | Idem. |
| Memel fir | ·553 | 2·5 | 1 | 1 | 1·15 | 218 | 545 | Idem. |
| Norway fir, from Longsound | ·639 | 2 | 1 | 1 | 1·125 | 396 | 792 | Idem. |
| Mar Forest fir | ·715 | 7 | 2 | 2 | 5·5 | 360 | 315 | Barlow. |
| Scotch fir, English growth | ·529 | 2·5 | 1 | 1 | 1·75 | 233 | 582 | By my trial. |
| Ditto, ditto | ·460 | 2·5 | 1 | 1 | | 157 | 392 | Ebbels. |
| Christiana white deal | ·512 | 2 | 1 | 1 | ·937 | 343 | 686 | By my trial. |
| American white spruce | ·465 | 2 | 1 | 1 | 1·312 | 285 | 570 | Idem. |
| Spruce fir, British growth | ·555 | 2·5 | 1 | 1 | | 186 | 465 | Ebbels. |
| American pine, Weymouth | ·460 | 2 | 1 | 1 | 1·125 | 329 | 658 | By my trial. |
| Larch, choice specimen | ·640 | 2·5 | 1 | 1 | 3 | 253 | 632 | Idem. |
| Ditto, medium quality | ·622 | 2·5 | 1 | 1 | | 223 | 557 | Idem. |
| Ditto, very young wood | ·396 | 2·5 | 1 | 1 | 1·75 | 129 | 322 | Idem. |

109. In these tables, as in all the others, I have endeavoured to collect experiments of such various kinds as would best show the strength of wood under different circumstances. I consider this much preferable to taking mean results; and it will convey much more useful information to the reader. It will be seen that the specimens from aged trees are much inferior in strength to those of mean age; and that the strength of green timber differs materially from that of seasoned, or dry. Also, that the strength is greater in those specimens which are the most heavy; but the increase of strength is not exactly proportional to the increase of specific gravity.

*Rules for the Strength of Beams supported at both Ends.*

110. To find the weight that would break a rectangular beam when applied at the middle of its length, the beam being supported at the ends.

RULE XI. Multiply the breadth in inches by the square of the depth in inches, divide this product by the length in feet, and the quotient multiplied by the value of $c$ in Table IX. corresponding to the kind of wood; the product will be the weight in pounds.

*Example.* The length of a girder of Riga fir between the supports is 21 feet, its depth is 14 inches, and breadth 12 inches; to find the weight that would break it when applied in the middle. Opposite Riga fir in the table we find $c=530$; and $\frac{12 \times 14 \times 14 \times 530}{21} = 59360$ pounds, or above 26 tons.

If a beam of the same scantling and length had been supported at one end only, one-fourth of the weight would have broken it.

111. To find the weight that would break a solid cylinder when applied at the middle of its length, the cylinder being supported at the ends.

RULE XII. Find the value of $c$ for the kind of wood in Table IX. art. 108, and divide it by $1 \cdot 7$; multiply the quotient by the cube of the diameter in inches, and divide the product by the length in feet; the quotient will be the weight in pounds that would break the cylinder.

*Example.* What weight would break a solid cylinder of ash, 12 feet long and 8 inches diameter. For ash the value of $c$ is 635 in the table, therefore $\frac{635 \times 8 \times 8 \times 8}{1 \cdot 7 \times 12} =$ 15937 pounds.

112. If the weight be uniformly diffused over the length of a beam, it will require to break it twice the weight that would break it when applied at the middle of its length.

### *Strength of Beams supported at one End.*

113. The rules for beams supported or fixed at one end are precisely the same as those for beams supported at both ends, except that a different constant number must be used; viz. the constant $d$ in the following table, or the constant for beams supported at both ends must be divided by 4. And when the weight is uniformly diffused over the length, the beam will bear double the weight that would break it when applied in the middle.

114. TABLE X.—*Experiments on the Strength of Beams supported at one End.*

| Kind of wood. | Specific gravity | Length in feet. | Breadth in inches. | Depth in inches. | Deflexion at the time of fracture in inches. | Weight that broke the piece in pounds. | Values of constant $d$. | Experimentalist. |
|---|---|---|---|---|---|---|---|---|
| English oak ...... | 922 | 4 | 2 | 2 | | 266 | 133 | Beaufoy. |
| Ditto ............ | | 4 | 2 | 2 | | 210 | 105 | Idem. |
| Dantzic oak ....... | ·854 | 4 | 2 | 2 | | 196 | 98 | Idem. |
| Beech ............ | ·700 | 3 | 2 | 2 | 11 | 401 | 150 | Barlow. |
| Ditto ............ | ·740 | 2 | 1 | 2 | 5 | 352 | 176 | Idem. |
| Ash ............. | ·658 | 3 | 2 | 2 | $11\frac{1}{2}$ | 436 | 163 | Idem. |
| Ditto ............ | ·730 | 2 | 1 | 2 | 6 | 321 | 160 | Idem. |
| Ditto, green ....... | ·858 | 5 | 2 | 2 | 16 | 239 | 149 | Peake and Barralier. |
| Teak, old, dry ..... | ·606 | 5 | 2 | 2 | $12\frac{1}{2}$ | 257 | 161 | Idem. |
| Riga fir .......... | ·537 | 4 | 2 | 2 | | 210 | 105 | Beaufoy. |
| Virginian yellow pine | ·522 | 5 | 2 | 2 | $11\frac{3}{4}$ | 147 | 92 | Peake and Barralier. |
| Canadian white pine | ·618 | 5 | 2 | 2 | $18\frac{3}{4}$ | 122 | 76 | Idem. |
| Pitch pine ........ | | 4 | 2 | 2 | | 270 | 135 | Beaufoy. |
| Larch, dry ........ | ·526 | 5 | 2 | 2 | $16\frac{1}{2}$ | 162 | 101 | Peake and Barralier. |

### *Resistance to Detrusion, or crushing across close to a fixed Point.*

115. There is another kind of cross strain that requires particular attention, as the strength of framing often depends upon it; that is, when a body is crushed across close to the points of support. Dr. Thomas Young has called the resistance to this kind of strain the "resistance to *detrusion.*"

According to the experiments of Professor Robison, this resistance appeared to be exactly proportional to the area of the section, and quite independent of its figure or

position*. Mr. Barlow has also made some experiments on this kind of resistance; from which it appears, that when the force is parallel to the fibres, the strength of fir to resist detrusion is from 556 to 634 pounds per square inch, or about one-twentieth of its direct cohesion in the direction of the fibres †. We have great reason to believe, that the resistance to being crushed across is, in all cases, equal, or very nearly equal, to the cohesive force of the body; and as, in construction, it is the lateral cohesion of timber that is usually exposed to a detruding force, we may conclude that the numbers already given (in art. 77) will be sufficient, with the one above stated, to assist the carpenter in proportioning the parts that have to support this strain.

116. To give an example of the application, let Ac (*fig.* 15, *Plate* II.) be the lower end of a principal rafter, and CB the tie beam. Now it is evident, that if the part D should not be made sufficiently long to resist the thrust of the foot of the rafter, it would crush off the abutment at the line *b*C. Let us, for the sake of simplicity, suppose there is not a tenon in the joint, then the horizontal thrust of the rafter in pounds should be equal to the area of the surface in inches, that would be forced asunder in the case of fracture, multiplied by the resistance of a square inch in pounds. But, in practice, the strain should be only one-fourth of the cohesive force; therefore, to find the length *b*C we have the following rule:

RULE XIII. Divide four times the horizontal thrust, by the thickness in inches, multiplied into the cohesive force of a square inch in pounds, and the quotient will give the length *b*C in inches.

*Example.* Find the horizontal thrust of a rafter, or any other oblique beam, by the principles detailed in Section I. (art. 40;) let us suppose this pressure is found to be 5600 pounds, and let the thickness of the beam be 6 inches; also, when the beam is of fir, the lowest number for the cohesive force is, according to Mr. Barlow's experiments, 556 pounds. Then $\frac{4\times5600}{6\times556}=6\cdot7$ inches nearly for the distance from *b* to C. If the beam had been oak, then the resistance of a square inch is 2316 pounds, from Table III. art. 77; therefore, $\frac{4\times5600}{6\times2316}=1\cdot7$ inches nearly. Further application of these principles will be found under the Section on Joints and Scarfing. Sect. IX.

## ON THE RESISTANCE TO COMPRESSION.

117. When a piece of timber is compressed in the direction of its length, it yields to the force in a different manner, according to the proportion between its length and the

* Encyclopædia Britannica, art. Strength of Materials.

† Essay on the Strength of Timber, &c. p. 79.

area of its cross section. For more convenient illustration, let us suppose the piece to be a cylinder, then if its length be greater than about eight times its diameter, the force will cause it to bend in the manner shown in *fig.* 35, *Plate* III.; and it will break at the middle of its length. But when the length of a wooden cylinder is less than about eight times its diameter, the piece will expand in the middle of its length, and split in several places. Materials that are less flexible than timber break in another different manner when in short lengths.

The case where the length exceeds about eight times the diameter is that which is most useful, consequently shall be first examined.

### *On the Strength of Columns and Posts to resist Flexure.*

118. It is certain, from experience, that there is a certain force that will bend a piece of timber when acting in direction of its length; and that, when it has been bent in a small degree, a still greater force is required to complete the fracture. But our investigation must be confined to the strength to resist the first degrees of flexure.

The strain will be directly as the weight or pressure; and inversely as the strength, which is inversely as the cube of the diameter. The strain will also be directly as the deflexion, which will be directly as the quantity of angular motion, and as the number of parts strained; that is, directly as the square of the length, and inversely as the diameter. Joining these proportions, and retaining the same notation as in the preceding investigations, we have $\frac{L^2 \times W}{D^4}$ is as the strain, and $1{\cdot}7\, a \times L^2 \times W = D^4$. (12.)

The strain being supposed constant.

When the post is rectangular, and D is the least side; then, $e \times L^2 \times W = BD^3$. (13.)

If the post be square, it will break in the direction of its diagonal; and, $4e \times L^2 \times W = D^4$. (14.)

Where D is the diagonal.

119. The stiffest rectangular post is that in which the greater side is to the less as 10 is to 6; therefore, when the post is insulated, this form should be preferred; but even when the post is of this form it will bend in two directions. In this case the equation (13.) becomes $0{\cdot}6e \times L^2 \times W = D^4$. (15.)

Where D is the least side. The greater side will be found by dividing the least by ·6.

120. When two inclined beams or rafters are strained by a weight resting upon the point where they meet, as in *fig.* 1, *Plate* I. the pressure in the direction of the beams may be found by art. 14 of Section I.; and substitute this pressure for W, in one of the preceding equations (12.) to (16.), from which the scantlings may be found that would be capable of sustaining these pressures. And, generally, let the pressure in the

direction of a beam be found by the principles in Section I. and the pressure thus found being substituted for W in the equations from (12.) to (16.) will enable the reader to find the scantlings that would support these pressures.

In these equations we have supposed the beams and columns to be perfectly straight; and that the pressure should be exactly in the direction of the axes: but it often happens that this cannot be the case; and as a very slight deviation causes a considerable difference in the magnitude of the strain, it is easy to account for the great irregularities which may be found in the few experiments that have been made on this strain.

Let AB, *fig.* 36, *Plate* III. represent a beam, supporting a load at A, and supported itself at the point B. Join AB, and if the line does not pass through the centre *c* of the cross section of the post or beam at the middle of its length, the strain will be much increased; because the weight acts with the energy of a lever. The same thing happens when the beam is not perfectly straight, as in *fig.* 35.

121. When a beam or post, that is not straight, is pressed in the direction of its length, or where the pressure acts with a leverage, as in *fig.* 36, the effect of this leverage must be considered.

Let C be the neutral point, *fig.* 35 and 36, which is situate nearly at the middle of the depth of the beam, then the leverage will be expressed by $L \times \cos. ACD$. Or denoting the angle ACD by $c$, it is $L \times \cos. c$. Hence the equations in art. 118, when applied to beams where the weight acts with a leverage, should be multiplied by this leverage as below. When the post is cylindrical, and D its diameter, $1 \cdot 7\, e \times L^3 \times W \times \cos. c = D^4$. (17.)

In a rectangular post or beam, where D is the least side, $e \times L^3 \times W \times \cos. c = BD^3$. (18.)

In a square post or beam, where D is the diagonal of the square, $4e \times L^3 \times W \times \cos. c = D^4$. (19.)

And equation (16.) art. 119, becomes $0 \cdot 6\, e \times L^3 \times W \times \cos. c = D^4$, and $B = \frac{D}{\cdot 6}$. (20.)

In these equations, when the beam becomes vertical, $\cos. c = 0$; therefore $L \times \cos. c = 0$, and the rules become the same as for vertical beams. Also when the deflexion is to be a constant quantity, these rules apply to a beam fixed at one end, either in an inclined or horizontal position, for it is obvious that the operation of the forces would not be altered by fixing the part of the beam, below CD, in a wall. When the beam is horizontal, $\cos. c = 1$.

It will be often more convenient to substitute another mode of expression in these equations; that is to say, the sine of CAD instead of cosine of ACD, then CAD may be called the angle which the neutral point makes with the direction of the pressure.

122. A column or pillar that shall be equally strong throughout will be generated by the revolution of two parabolas round the axis of the column, the vertices of the curves being at the extremities, as is shown in *fig*. 37; for when all the other quantities are constant, $L^2 : D^4$, or $L : D^2$, a property of the parabola.

But the figure of a column depends on two conditions: the one, that it shall rest firmly on its base, and offer a solid bearing for the load to be supported; the other, that it shall be capable of the greatest degree of resistance. To fulfil the first condition, it should be a frustum of a cone; to fulfil the second, it should be of the form generated by the revolution of two parabolas: and combining the forms which fulfil these conditions, we produce nearly that form which has been adopted for columns; that is, a column with a slight swell in the middle. But where the form of a column is considered rather as the most beautiful than the strongest, one that gradually diminishes from the base to the capital appears preferable.

### *Experiments on the Stiffness of Beams to resist Compression.*

123. The experiments are few on this strain, indeed it is difficult to make such experiments without an expensive apparatus, and without they are made with much care they are of little value. The following tables contain the results of the most valuable for our present purpose*. The weight that produced the first degree of deflexion, and the weight that broke the piece, are given in the tables; but that producing the first deflexion is the one of the greatest importance.

* Experiments on this strain should always be made either with cylinders, or beams sufficiently thin to cause the deflexion to be in one direction only.

TABLE XI.—*Experiments on the Resistance of Beams to Forces pressing in the Directions of their Lengths.*

| Kind of wood. | Length in feet. | Breadth in inches. | Thickness in inches. | Deflexion in inches. | Weight producing the deflexion in pounds. | Values of *e*. | Duration of the experiments in hours. | Weight that broke the piece in pounds. | Experimentalist. |
|---|---|---|---|---|---|---|---|---|---|
| Oak, seasoned | 2·125 | 2·126 | 2·126 | ·0787 | 7,856 | ·0006 | 4 | 15,631 | Lamandé.* |
| | | | | ·03937 | 13,525 | ·00033 | 6 | 21,296 | |
| | | | | ·1181 | 14,119 | ·00032 | 18 | 19,993 | |
| | | | | ·03937 | 11,750 | ·00042 | 8 | 21,060 | |
| Ditto, ditto .. | 4·25 | 2·126 | 2·126 | ·0787 | 6,298 | ·0002 | 21 | 11,844 | Idem. |
| | | | | ·1574 | 6,298 | | 27 | 12,225 | |
| | | | | ·1574 | 6,298 | | | 13,565 | |
| | | | | ·1574 | 6,298 | | 6 | 12,458 | |
| Ditto, ditto .. | 6·375 | 2·126 | 2·126 | ·1574 | 3,277 | ·00015 | 6 | 7,244 | Idem. |
| | | | | ·1574 | 2,860 | ·00018 | | 7,484 | |
| | | | | ·2361 | 2,750 | ·00019 | 5 | 8,492 | |
| | | | | ·1574 | 2,750 | | | 7,878 | |
| Ditto, ditto .. | 2·125 | 3·18 | 3·18 | ·0787 | 34,599 | ·0007 | 27 | 50,958 | Idem. |
| | | | | ·03937 | 45,168 | ·0005 | 24 | 50,958 | |
| Ditto, ditto .. | 4·25 | 3·18 | 3·18 | ·1574 | 20,317 | ·0003 | 29 | 43,639 | Idem. |
| | | | | ·1574 | 18,647 | ·00031 | 5 | 36,865 | |
| | | | | ·19685 | 20,578 | ·0003 | 9 | 36,205 | |
| | | | | ·27559 | 21,819 | .00026 | 17 | 28,182 | |
| Ditto, ditto .. | 6·375 | 3·18 | 3·18 | ·1574 | 9,121 | ·00028 | 7 | 26,939 | Idem. |
| | | | | ·19685 | 9,713 | ·00027 | 19 | 28,987 | |
| | | | | ·0787 | 11,000 | ·00023 | 4 | 23,929 | |
| | | | | ·2361 | 10,142 | ·00025 | 18 | 33,048 | |
| | | | | ·1574 | 12,746 | ·0002 | 6 | 36,902 | |
| Ditto, ditto .. | 2·125 | 4·25 | 4·25 | ·0787 | 61,883 | ·00118 | 11 | 95,262 | Idem. |
| | | | | ·03937 | 56,691 | ·00129 | 8 | 66,112 | |
| | | | | ·03937 | 56,693 | | 23 | 105,826 | |
| | | | | ·0787 | 67,467 | ·00107 | 28 | 94,476 | |
| | | | | ·03937 | 57,780 | ·00125 | 30 | 88,442 | |
| Ditto, ditto .. | 4·25 | 4·25 | 4·25 | ·03937 | 63,066 | ·00027 | 8 | 100,755 | Idem. |
| | | | | ·0787 | 29,695 | ·0006 | 5 | 85,998 | |
| | | | | ·0787 | 50,525 | ·00035 | 19 | 73,238 | |
| | | | | ·03937 | 45,201 | ·0004 | 19 | 96,368 | |
| Ditto, ditto .. | 6·375 | 4·25 | 4·25 | ·1574 | 21,586 | ·00038 | 7 | 64,090 | Idem. |
| | | | | ·2361 | 17,331 | ·00047 | 5 | 59,373 | |
| | | | | ·1574 | 18,517 | ·00044 | 22 | 54,062 | |
| | | | | ·2361 | 27,599 | ·0003 | 22 | 65,608 | |

* Gauthey's Construction des Ponts, tom. ii. p. 48.

124. TABLE XII.—*Experiments on the Resistance of Timber when compressed in the Direction of its Length.*

| | Kind of wood. | Specific gravity. | Length in feet. | Breadth in inches. | Thickness in inches. | Deflexion in inches. | Weight producing the deflexion in pounds. | Values of *e*. | Duration of the experiments in hours. | Weight that broke the piece in pounds, or remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Oak | 1·038 | 8·52 | 6·22 | 5·06 | 0·268 | 38,105 | 0·00029 | 0·83 | Recovered its first form. |
| 3 | Ditto | 1·010 | 8·52 | 6·22 | 4·00 | 0·09 | 26,381 | 0·0002 | 0·83 | Retained a slight flexure. |
| 4 | Ditto | 1·000 | 8·52 | 5·24 | 3·9 | 0·445 | 26,384 | 0·00016 | 6·66 | Idem. |
| 5 | Ditto | ·923 | 8·52 | 5·15 | 4·17 | 0·665 | 26,392 | 0·00019 | 6·66 | 50,448 |
| 7 | Ditto | ·973 | 7·46 | 6·22 | 5·06 | Not sensible. | 38,098 | 0·00038 | 0·83 | |
| | | | | | | 0·157 | 50,454 | 0·00028 | 2·08 | Recovered its first form. |
| 8 | Ditto | ·972 | 7·46 | 6·13 | 4·09 | 0·244 | 38,104 | 0·00019 | 12·08 | 72,865 |
| 9 | Ditto | ·925 | 7·46 | 6·22 | 4·00 | 0·267 | 38,106 | 0·00018 | 12·08 | 62,977 |
| 10 | Ditto | 1·038 | 7·46 | 4·97 | 4·00 | 0·312 | 26,397 | 0·00021 | 10·00 | Retained a slight flexure. |
| 11 | Ditto | 1·102 | 6·39 | 6·13 | 5·24 | 0·177 | 38,107 | 0·00057 | 7·08 | Idem. |
| 13 | Ditto | ·987 | 6·39 | 6·22 | 4·00 | 0·177 | 38,106 | 0·00025 | 2·08 | Recovered its first form. |
| 15 | Ditto | 1·032 | 6·39 | 5·24 | 4·17 | 0·22 | 38,048 | 0·00024 | 10·00 | Idem. |
| 17 | Ditto | ·920 | 7·46 | 6·22 | 4·25 | 0·114 | 26,396 | 0·00032 | 10·00 | Idem. |
| 19 | Ditto | 1·038 | 8·52 | 6·22 | 5·06 | 0·177 | 26,392 | 0·00042 | 10·00 | |
| 20 | Ditto | ·944 | 8·52 | 7·37 | 6·22 | 0·09 | 26,394 | 0·0009 | 10·00 | Recovered its first form. |
| 21 | Ditto | ·842 | 8·52 | 7·46 | 6·22 | 0·09 | 26,396 | 0·00093 | 10·00 | |

The numbers in the first column correspond with those of the experiments I have selected from M. Girard's work *. Many of his experiments were made with defective specimens, these are rejected, because pieces so defective should not be employed in any situation where they are exposed to much strain. By description and plates representing the most defective specimens, he has rendered it easy to ascertain the cause of many of the irregularities in his experiments. The least deflexion only, with the weight that produced it, is given for each piece in the table above; several other deflexions were observed, but the first is the only one that is of use for the purpose of determining the strength of posts or columns. Most of the specimens bent in the direction of the diagonal, consequently they were curved both in the direction of the breadth and thickness. The deflexion given above is that in the direction of the thickness, except in one case, which is experiment 19; in that case the force cannot have been applied exactly in the direction of the axis. Some of the pieces were broken; in those cases the

* Traité Analytique de la Résistance des Solides, table i.

weight that broke the piece is given. It is remarkable that the weight which broke the specimen is always about twice that which produced the first deflexion, both in Girard's and Lamandé's experiments.

M. Girard has not described the state of the wood when his trials were made, but it appears from a remark he makes on the 8th experiment, that it had been cut about fifteen months*; consequently it would not be very dry, as might be inferred from the weight of the cube foot given in the third column.

In the 11th column the effect of the greatest load that was tried is stated for some of the pieces. No. 1 recovered its first form after being loaded with 93,320 pounds. No. 3 retained a slight flexure, the greatest weight it bore being 68,946 pounds.

It is obvious that a column or post should not be loaded till the deflexion becomes sensible, therefore the values of $e$ as found by these experiments are too low for use. The constant number $e$ then should be taken of such a value as may give all the security that is necessary, without employing more timber than is consistent with just economy.

The highest value of $e$ is 0·00125 in Lamandé's experiments, and it is 0·00093 in Girard's. If the number be taken 0·0015 the result will always be sufficiently strong for use, as in good timber it would seldom be loaded with above one-fourth of the weight that would produce sensible flexure, if its strength were determined by the rule.

Experiments having been made upon oak only, it remains to determine the constant number $e$ for other kinds of wood. It has been shown by Dr. Thomas Young†, that the weight, W, which would hold a beam in equilibrium, under a small degree of flexure, is expressed by $\frac{\cdot 8225 d^2 g}{l^2}$; where $d$ is the least side, $l$ the length, and $g$ the weight of the modulus of elasticity corresponding to the area of the section; consequently, if $m$ be the weight of the modulus for a square inch (see Sect. X. art. 369) then $g = mbd$, where $b$ is the breadth: and the formula becomes $\frac{\cdot 8225 bd^3 m}{l^2} = W$; or

$$\frac{Wl^2}{\cdot 8225 m} = bd^3.$$

According to my experiments the modulus of elasticity of oak of a medium quality is 1,714,500 pounds; and recollecting that in Dr. Young's formula $l$ is in inches, we have

$$\frac{144 Wl^2}{\cdot 8225 \times 1{,}714{,}500} = Wl^2 \times 0{\cdot}000102 = bd^3.$$

* Traité Analytique, &c art. 235.

† Lectures on Natural Philosophy, vol. ii. art. 323; and the same thing is shown in the article Carpentry. prop. B, Supplement to the Encyclopædia Britannica, 1818.

There is no doubt that from experiments made with dry oak of such a quality as that from which the weight of the modulus was obtained, and made with all the precision that might be employed on a small scale, the constant number given by this formula would agree with the experiments*.

As the modulus of elasticity has been determined for several kinds of wood, Dr. Young's formula enables us at once to obtain the constant number for other woods, when that for one kind is obtained from experiments. Assuming therefore that 0·0015 is the proper constant number for oak, the following table will show those for other woods. The first column gives the kind of wood; the second its modulus of elasticity for a square inch in pounds avoirdupois; and the third contains its constant number, to be employed in the rules for the strength of posts and columns.

TABLE XIII.—*Of the constant Numbers to be used in calculating the Dimensions of Columns, Posts, and other Beams, pressed in the Direction of their Length.*

| Kind of wood. | Modulus of elasticity in pounds. | Value of $e$, the constant number in the rules. |
|---|---|---|
| English oak | 1,714,500 | 0·0015 |
| Beech | 1,316,000 | 0·00195 |
| Alder | 1,086,750 | 0·0023 |
| Chesnut, green | 924,570 | 0·00267 |
| Ash | 1,525,500 | 0·00168 |
| Elm | 1,343,000 | 0·00184 |
| Acacia | 1,687,500 | 0·00152 |
| Mahogany, Spanish | 1,255,500 | 0·00205 |
| Ditto, Honduras | 1,593,000 | 0·00161 |
| Teak | 2,167,074 | 0·00118 |
| Cedar, Lebanon | 486,000 | 0·0053 |
| Riga fir | 1,687,500 | 0·00152 |
| Memel fir | 1,957,750 | 0·00133 |
| Norway spruce fir | 1,804,000 | 0·00142 |
| Weymouth pine | 1,633,500 | 0·00157 |
| Larch | 1,363,500 | 0·0019 |

* There are many reasons for giving the preference to experiments made on a small scale. All the measures can be taken with more accuracy, the weight can be made to act directly upon the specimens, consequently there is no loss nor uncertainty from friction of mechanical powers, the necessary adjustments can be made with more precision, and the whole process is more completely under the eye of the observer. The apparatus being simple, the labour of calculation is abridged, trials are more easily repeated and varied, and the expense becomes comparatively small. For similar reasons a mineral can be more accurately analyzed by employing a few grains, than by trying upon a larger quantity; and I know no reason why a well chosen specimen of wood should not afford as accurate a measure of the elasticity of that substance, as a small specimen of limestone does of the constituents of the mass it had been selected from. But the specimens of wood should not be less than an inch square, otherwise they become too small to contain fair specimens of the wood.

In the oak and fir the constant numbers do not differ materially, but in small scantlings oak is more liable to warp, and besides oak is seldom so straight grained or so free from knots as yellow fir; therefore it is usually employed in larger scantlings. But this must depend on the judgment of those who are to use it.

*Practical Rules for the Strength of Columns, Posts, and other Beams, pressed in the Directions of their Lengths.*

125. To find the diameter of a column or pillar that will sustain a given weight, when the pressure is in the direction of the axis.

RULE XIV. Multiply the weight or pressure in pounds by 1·7 times the value of $e$ for the kind of wood taken from Table XIII. art. 124; then multiply the square root of the product so obtained by the length or height in feet, and the square root of the last product will be the diameter required in inches.

If the column be shorter than 10 times its diameter, then the diameter found by this rule will be too small. In this case the proper diameter will be found by Rule XVIII. art. 131.

*Example.* Let it be required to support 12 tons (26880 pounds) by a cylindrical oak post, of which the height is 8 feet. Then, by the preceding table (Table XIII.) the value of $e$ for oak is 0·0015; therefore, $26880 \times 1{\cdot}7 \times 0{\cdot}0015 = 68{\cdot}544$, of which the square root is 8·28 nearly. And $8{\cdot}28 \times 8 = 66{\cdot}24$; the square root of 66·24 is very nearly 8·14, therefore 8·14 inches is the diameter required.

126. To find the scantling of a rectangular post or beam capable of sustaining a given pressure in the direction of its length.

RULE XV. Multiply together the weight or pressure in pounds, the square of the length in feet, and the value of $e$ for the kind of wood from Table XIII. Divide this product by the breadth in inches, and the cube root of the quotient will be the thickness in inches.

In this rule, as in the last, when the beam or post is shorter than 10 times its thickness or least dimension, the scantling found by this rule is too small. The proper scantling in such cases may be found by Rule XVIII. art. 131, where the cause of this limitation is explained.

*Example.* Let the height of a post of Memel fir be 8 feet, its breadth 7 inches, and the weight to be supported 12 tons, or 26880 pounds. The value of $e$ by Table XIII. for Memel fir is 0·00133; therefore $\frac{26880 \times 0{\cdot}00133 \times 8 \times 8}{7} = 327$ nearly; and the cube root of 327 is 6·889 inches, the thickness required.

127. If the beam be curved, or the weight does not press exactly in the direction of

the axis of the beam, then find the cosine of the angle ACD, or the sine CAD, *fig.* 35 and 36, to a radius of unity.

RULE XVI. Multiply together the weight in pounds, the tabular value of $e$ for the kind of wood, and the sine of the angle CAD; divide the product by the breadth in inches. The cube root of the quotient multiplied by the length in feet will give the depth in inches.

*Example.* Let the length AB be 8 feet, the weight 26880 pounds, the breadth 7 inches, and the sine of CAD$=\cdot 25$. Also let $\cdot 0015$ be the tabular number, as in the example, art. 125. Then $\frac{26880\times\cdot 0015\times\cdot 25}{7}=1\cdot 44$. The cube root of $1\cdot 44$ is $1\cdot 13$ nearly; and $1\cdot 13\times 8=9\cdot 04$ inches, the depth required.

A post 8 inches diameter would not support half the weight when applied as it is supposed to be in this example; but we have seen that it is sufficiently strong when the force acts in the direction of the axis. See art. 126.

Sometimes the strain arises from pressure produced by the position of the beams, as in *fig.* 1 or 3, *Plate* I.; in that case the pressure in the direction of the beam must be found by the rules in Section I.; and this pressure must be substituted instead of the weight, observing that the pressure must be found in pounds.

### *Strength of Curved Ribs.*

128. When a curved rib is of the proper curve of equilibrium for the constant load upon it, as in a bridge for example, there are often strains caused by variable loads, such as heavy waggons and the like. The effect of such loads upon a continued rib is the next object of our inquiry.

Let ACB (*fig.* 27, *Plate* III.) be the rib, and let a load W be applied in the middle at C. The effect of such a load would be to depress the curve at C, and to cause it to rise at $e$ and $f$; dividing the curve into 4 equal parts. Denoting the length of each part by $l$, then 2DC : AC : : W : pressure in the direction AC$=\frac{W\times AC}{2DC}$, and $e\times 8l^3\times\frac{W\times AC}{2DC}\times$ sine $eCa=BD^3$, or $2l\times\left(\frac{e\times W\times AC\times \sin. eCa}{B\times 2DC}\right)^{\frac{1}{3}}=D$. But here it may be observed, that no notice is taken of the resistance at C; because it is not possible to join large pieces so as to make them equally as strong as a solid beam of one piece, therefore, to keep the rule as simple as possible, I have considered the strength at C to compensate for the defects of a built rib.

But the strain upon the rib will not be greatest when the weight is applied in the

middle. The exact point where the strain is greatest has not been ascertained, but it will be near enough for practice to fix this point at the distance of one-third of the span from one of the abutments.

*Practical Rule and Example.*

Let the weight be considered to act at E, *fig.* 27. then (by art. 14, Sect. I.) if the weight be represented by EF, the pressure in the direction EA will be represented by EA. Or, EF : EA : : W : pressure. Taking an example in numbers, let EF be 77 feet, and EA 135, W being 50,000 pounds. Then 77 : 135 : : 50,000 : 87,662 pounds, the pressure required.

RULE XVII. To find the scantling of the rib. Multiply together the pressure in pounds, the constant $e$ from the table art. 124, and the sine of the angle $d\mathrm{E}h$ to a radius of unity. Divide the product by the breadth in inches of all the ribs the weight will bear upon. The cube root of the quotient multiplied by the distance AE, in feet, will give the depth of the rib in inches.

*Example.* In a bridge of 200 feet span, consisting of 3 ribs, each 24 inches, or the whole breadth of the ribs 72 inches. The sine of $d\mathrm{E}h=0{\cdot}1$, and the constant number from Table XIII. art. 124, corresponding to oak=0·0015. The pressure in the direction EA being 87,662 pounds as above found. Then $\frac{87662 \times {\cdot}0015 \times 0{\cdot}1}{72}=0{\cdot}18263$. The cube root of 0·18263 is 0·587 nearly; and the distance AE is nearly 135 feet. Therefore, $0{\cdot}587 \times 135=79$ inches, the depth required.

129. It has already been stated, that the stiffest rectangular post or beam is that of which the sides are to one another as 10 to 6 (see art. 119 :) the rule expressed in words at length may be useful.

RULE. Multiply the weight or pressure in pounds by 0·6 times the tabular number $e$ for the kind of wood, from Table XIII. art 124. Extract the square root of this product, and multiply the root by the length in feet. The square root of the last product will be the least side in inches.

Divide the less side by 0·6, which will give the greater side.

*Example.* It is required to support a part of a wall by an oak post, 11 feet in length. The wall to be supported contains a rod of reduced brickwork which weighs 13 tons, or 29120 pounds; and it is proposed to determine the scantling of the post so as to be sufficient to sustain the pressure. According to the rule, $29120 \times 0{\cdot}6 \times 0{\cdot}0015=20{\cdot}208$. The square root of 20·208 is nearly 4·5; therefore $4{\cdot}5 \times 11=49{\cdot}5$. The square root of 49·5 is 7·03, consequently the least side of the post should be 7·03 inches. And $\frac{7{\cdot}03}{0{\cdot}6}$ $=11{\cdot}7$ inches, the greater side; therefore a post 11 feet long, of which the scantling is $11\frac{3}{4}$ inches by 7 inches, would support a rod of brickwork with safety.

A post that sustains a considerable burden should never be exposed to a cross strain; as a very small force of this kind has a considerable effect when the post is compressed in direction of its length.

A table of the scantlings of story posts is given at the end of the volume; but story posts depend so much on the nature of the building to be supported, that it would be difficult to reduce them to particular rules; it will not, however, be difficult to estimate, with sufficient accuracy, the weight a post of this kind may have to support, and then the scantling will be found by the preceding rules.

### *On the Resistance to Crushing.*

130. According to the experiments of Rondelet, when the height of a square post is less than about 7 or 8 times the side of its base, it cannot be bent by any pressure less than that which would crush it. The internal mechanism of the resisting forces, when timber yields by crushing, is not exactly understood, but it appears evident that it is different in timber from what it is in stone, and other brittle materials. In timber the resistance to crushing is less than the cohesive force; in brittle bodies it is always greater than the cohesive force of the material; but it must not be imagined that the resistance to crushing is an exception to the laws of compression, because the resistance to extension, and that to compression, are both employed in opposing a force tending to crush the body when the body is of a flexible nature.

The resistance of timber to crushing appears to increase in a higher ratio than that of the area of its section. We have not, however, experiments that will throw any light on this part of the subject; and the generality of writers content themselves with assuming the strength to be directly as the area.

According to the experiments of Rondelet, made on cubes of an inch in length, it required from 5000 to 6000 pounds per square inch to crush oak; and under this pressure its length was reduced more than one-third. For to crush fir it required from 6000 to 7000 pounds per square inch; and the length was reduced one-half*.

Mr. George Rennie's trials afforded results considerably lower than those of Rondelet. The following are the results of his experiments:

| | | |
|---|---|---|
| A cubical inch of elm was crushed by | .... | 1284 pounds. |
| .............. | American pine ........ | 1606 |
| .............. | white deal ........... | 1928 |
| .............. | English oak .......... | 3860 |
| .............. | ditto, 4 inches long .... | 5147† |

* L'Art de Bâtir, tome iv. p. 67.

† Philosophical Transactions for 1818, part i. p. 130.

131. The load a piece of timber will bear when pressed in the direction of its length, without risk of being crushed, may be found by the following rule.

RULE XVIII. Multiply the area of the piece of timber, in inches, by the weight that has been found capable of crushing a square inch of the same kind of wood (see the preceding experiments, art. 130.) Then one-fourth of the product will give the load in pounds that the piece would bear with safety.

*Example.* Required the weight that a piece of oak 3 inches by 2 inches would support with safety? Here the area is $3 \times 2 = 6$ inches; and by one of Mr. Rennie's experiments an inch square of oak is crushed by 3860 pounds. Consequently $\frac{6 \times 3860}{4} = 5790$ pounds, the weight required.

If the area that would support a given weight be required, divide 4 times the weight by the number of pounds that would crush a square inch, and the quotient is the area in inches.

By comparing the rule for the resistance to flexure with that for the resistance to crushing, it will be easy to determine the length when these rules give the same result. This comparison is important, because the strength of pieces shorter than this length must be calculated by the rules for the resistance to crushing; but all pieces longer than this length must be calculated by the rule for the resistance to flexure.

Let the force that would crush a square inch be represented by $f$, then by the preceding rule (Rule XVIII.) $\frac{D \times B \times f}{4} = W$. Also by equation (13.) (art. 118) we have $\frac{D^3 \times B}{L^2 \times e} = W$. Hence $\frac{D \times B \times f}{4} = \frac{D^3 \times B}{L^2 \times e}$, or $L^2 = \frac{4D^2}{f \times e}$, and $L = 2D\sqrt{\frac{1}{f \times e}}$.

From the experiments on crushing it appears, that $f$ may be taken at 4000 pounds for either fir or oak; and, according to Table XIII. art. 124, the value of $e$ is nearly the same for fir as it is for oak, viz. 0·0015. Putting these numbers in the equation $L = 2D\sqrt{\frac{1}{f \times e}}$, we have $L = 2D\sqrt{\frac{1}{4000 \times 0{\cdot}0015}} = 0{\cdot}818D$, nearly: that is, the length in feet is 0·818 times the least thickness in inches, when the resistance to flexure and the resistance to crushing are equal. Or, what is the same thing, the length is nearly 10 times the least thickness when the resistances are the same. Consequently, when the length of a beam is greater than 10 times the thickness, its strength must be determined by art. 125, 126, or 127. When it is less than 10 times the least thickness, the strength must be determined by Rule XVIII. of this article.

*On the Resistance to Compression at the Joints of Framing.*

132. There is yet another kind of resistance to compression to be considered; which is, when the end of one piece is pressed against the side of another piece. The strength of the joints of framing depends in some degree on this kind of resistance; for unless the resistance at the joint be equal to the pressure, a degree of compression may take place that would produce considerable derangement in the framing, if not a total failure.

In order to obtain some information on this important point, I made the following experiments: I prepared two pieces of good Memel fir, and placing the end of the one piece upon the side of the other, I loaded it successively with 800, 900, 1000, 1100, 1200, and 1300 pounds upon a square inch, examining the effect of each trial; the impression was faint with 900 pounds, but became very distinct with 1000 pounds; therefore I consider the pressure on the joints of timbers of yellow fir should never be greater than 1000 pounds per square inch. The position of the annual rings makes a considerable difference, for in some other trials the impression was very distinct with 950 pounds.

English oak was next tried; with a load of 1400 pounds the impression appeared to be about the same as 1000 pounds produced in Memel fir; and there was less difference from varying the position of the rings.

It is obvious that the pressure on the joints must limit the rules for the resistance of beams compressed in the direction of their length, nearly in the same manner as in the last article; with this difference, that the area of the joint is seldom equal to the area of the section of the beam. But if $B \times D$ be the area of the section of the beam, the area of the joint may always be expressed by $n \times B \times D$. Consequently, $n \times B \times D \times F = \frac{B \times D^3}{L^2 \times e}$; and $L = D\sqrt{\frac{1}{n \times F \times e}}$; where F is the force that produces a sensible impression.

Hence it appears, that in fir the least thickness of the beam in inches multiplied by $10\sqrt{\frac{1}{n}}$ is equal to the length in inches, when the resistance of the beam and that of the joint are equal; and $8{\cdot}3\sqrt{\frac{1}{n}}$ multiplied by the breadth gives the length for oak framing.

Let the area of the joint be half the area of a section through the beam, then $n = \frac{1}{2}$ and $\sqrt{\frac{1}{n}} = \sqrt{2} = 1{\cdot}414$. Hence when the area of the joint is in this proportion, in a fir frame, when the length is less than 14 times the least thickness, the scantling must be regulated by the size of the joint instead of the resistance to flexure.

# SECTION III.

## OF THE CONSTRUCTION OF FLOORS.

133. THE timbers which support the flooring boards and ceiling of a room are called, in carpentry, the *naked flooring*. There are different kinds of naked flooring, but they may be all comprised within the three following ones; viz. Single joisted floors, double floors, and framed floors.

1st. Single joisted floors. A single joisted floor consists of only one series of joists. *Plate* IV. *fig*. 38, shows a section across the joists of a single joisted floor.

Sometimes every third or fourth joist is made deeper, and the ceiling joists fixed to the deep joists, and crossing them at right angles. This is an improvement in a situation where there is not space for a double floor. *Fig*. 39 shows a section of a floor of this kind. It increases the depth of the floor very little, and will not allow sounds to pass so freely as a single joisted floor, and the ceilings will stand better. The ceiling joists, *a*, *a*, are notched to the deep joists *b*, *b*, *b*, and nailed.

134. 2ndly. Double floors. A double floor consists of three tiers of joists; that is, binding joists, bridging joists, and ceiling joists; the binding joists are the chief support of the floor, and the bridging joists are notched upon the upper side of them; the ceiling joists are either notched to the under side, or framed between with chased mortises; the best method is to notch them. *Fig*. 40 shows a section of a double floor across the binding joists, *b*, *b*, *b*. The bridging joists *d d* are notched over, and the ceiling joists *a a* are notched under the binding joists.

135. 3rdly. Framed floors differ from double floors only in having the binding joists framed into large pieces of timber, called girders. *Fig*. 41 shows a section across the girders of a framed floor; where *b*, *b*, *b*, are the binding joists.

Single joisting makes a much stronger floor, with the same quantity of timber, than a double or framed floor, and may be constructed with equal ease to the same extent of bearing; but the ceilings are more subject to cracks and irregularities; consequently single joisted floors of long bearings can be used only in inferior buildings.

When it is desirable to have a perfect ceiling, a double floor is used; and when the bearing is long, a framed floor becomes the most convenient. The following experiment was made on the comparative strength of framed and single joisted floors by Professor Robison.

136. Two models were made 18 inches square, one consisted of single joists, the other framed with girders, binding joists, bridging and ceiling joists; the single joists of the one contained the same quantity of timber with the girders alone of the other.

They were placed in a wooden trunk 18 inches square within, with a strong projection on the inside for the floors to rest on; and small shot was gradually poured over.

The single joisted floor broke down with 487 pounds, the framed floor with 327 pounds*. The difference would not be quite so much on a large scale, because the girders would not be so much weakened by mortises. This is not the only case where apparent strength has turned out to be real weakness; and shows how necessary it is to distinguish those parts which really support a load from those which only appear to do so.

## OF SINGLE JOISTED FLOORS.

137. In order to make a strong floor with a small quantity of timber, the joists should be thin and deep; but a certain degree of thickness is necessary, for the purpose of nailing the boards, and two inches is perhaps as thin as the joists ought to be made; though sometimes they are made thinner.

To find the depth of a joist, the length of bearing and breadth being given, for a single joisted floor.

RULE. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 2·2 for fir, or 2·3 for oak, will give the depth in inches†.

*Example.* Required the proper depth for a fir joist, the bearing being 12 feet and the breadth 2 inches? $\frac{12\times 12}{2}=72$, and the cube root of 72 is 4·16; therefore $4{\cdot}16\times 2{\cdot}2=$ 9·152 inches, the depth required; or 9 inches is near enough in practice.

On account of flues, fire-places, and other causes, it often happens that the joists cannot have a bearing on the wall. In such cases a piece of timber, called a *trimmer*, is framed between two of the nearest joists that have a bearing on the wall. Into this trimmer the ends of the joints to be supported are mortised. This operation is called *trimming*. The scantlings of trimmers may be found by the same rule as those for binding joists, Case 2, art. 150; the length of the joists framed into the trimmer being equivalent to the distance apart in binding joists.

* Encyclopædia Britannica, art. Roof, sect. 47.

† The constant numbers in this, and in all the rules for flooring and roofing, are derived from the scantlings of timbers that were found to be sufficiently strong; this I considered to be the best method of obtaining those numbers, because it is difficult to calculate the weight that a floor has to support; yet it is easy to ascertain whether a floor be sufficiently stiff or not after it is executed. These comparisons have not been made from single observations, but from various ones on bearings of very different lengths. The constant numbers are taken higher for oak, because the oak is seldom straight grained, and very subject to warp.

The two joists which support the trimmer are called *trimming joists,* and they should be stronger than the common joists. In general it will be sufficient to add one-eighth of an inch to the thickness of a trimming joist for each joist supported by the trimmer. Thus, if the thickness of the common joists be 2 inches, and a trimmer supports 4 joists, then add four-eighths, or half an inch; that is, make the trimming joists each $2\frac{1}{2}$ inches in thickness.

When the bearing exceeds 8 feet, single joisting should be strutted between the joists to prevent them turning or twisting sideways, and also to stiffen the floor; when the bearing exceeds 12 feet, two rows of struts will be necessary; and so on, adding another row of struts for each increase of 4 feet in bearing. These struts should be in a continued line across the floor, and short ends of boards, put in moderately tight, and nearly of the depth of the joists, are quite sufficient; indeed such pieces simply nailed are better than keys mortised into the joists, because they require less labour, and do not weaken the joists with mortises. The well fitting of the struts is an essential part in making a good ceiling.

For common purposes single joisting may be used to any extent that timber can be got deep enough for; but where it is desirable to have a perfect ceiling, the bearing should not exceed 15 feet. Also, where it is desirable to prevent the passage of sound, a framed floor is necessary.

## Of Framed Floors.

### *Girders.*

138. The girders are the chief support of a framed floor, and their depth is often limited by the size of the timber; therefore, the method of finding the scantling may be divided into two cases.

*Case* 1. To find the depth of a girder when the length of bearing and breadth of the girder are given.

Rule. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 4·2 for fir, or by 4·34 for oak, will give the depth required in inches.

139. *Case* 2. To find the breadth when the length of bearing and depth are given.

Rule. Divide the square of the length in feet, by the cube of the depth in inches; and the quotient multiplied by 74 for fir, or by 82 for oak, will give the depth in inches.

*Example to Case* 2. Let the bearing be 20 feet, and the depth 13 inches; to find the breadth, so that the girder shall be sufficiently stiff.

The cube of the breadth is 2197, and the square of the length is 400; therefore $\frac{400}{2197} \times 74 = 13{\cdot}47$ inches, the breadth required.

In these rules the girders are supposed to be 10 feet apart, and this distance should never be exceeded; and should the distance apart be less or more than 10 feet, the breadth of the girder should be made in proportion to the distance apart.

Girders should always, for long bearings, be made as deep as they can be got; an inch or two taken from the height of a room is of little consequence compared with a ceiling disfigured with cracks, besides the inconvenience of not being able to move in the rooms above without shaking every thing in them.

140. When the breadth of a girder is considerable, it is often sawn down the middle and bolted together with the sawn side outwards; the girders in the section, *fig.* 41, are supposed to be done in this manner. This is an excellent method, as it not only gives an opportunity of examining the centre of the tree, which in large trees is often in a state of decay, but also reduces the timber to a smaller scantling, by which means it dries sooner, and is less liable to rot. The slips put between the halves, or flitches, should be thick enough to allow the air to circulate freely between them. It is generally imagined that it strengthens a girder to cut it down, reverse it, and bolt it together again; it is in fact weakened by the operation, but the method is recommended here for the reasons above stated.

Others suppose that girders are cut down merely for the purpose of equalizing their stiffness; but admitting a girder to be bent considerably, the difference between the deflexions at any two points equally distant from the middle would not be sensible in girders of the usual form. The person who first practised the method of cutting girders down the middle undoubtedly did it with the view of preserving, and not of stiffening them. We find that Vitruvius, the oldest author on architecture extant, directs a space of two fingers' breadth to be left between the beams for forming the architrave over columns, in order that the air may circulate between and prevent decay*. Every one must have observed that decay begins in the first place at the joints, and other parts where the pieces are neither perfectly close nor yet sufficiently open to allow any dampness to evaporate.

141. When the bearing exceeds about 22 feet it is very difficult to obtain timber large enough for girders; and it is usual, in such cases, to truss them. The methods in general adopted for that purpose have the appearance of much ingenuity; but, in reality, they are of very little use. If a girder be trussed with oak, all the strength that can possibly be gained by such a truss consists merely in the difference between the compressibility of oak and fir, which is very small indeed; and unless the truss be

* Vitruvius, lib. iv. cap. 7.

extremely well fitted at the abutments, it would be much stronger without trussing. All the apparent stiffness obtained by trussing a beam is procured by forcing the abutments, or, in other words, by cambering the beam. This forcing cripples and injures the natural elasticity of the timber; and the continual spring, from the motion of the floor, upon parts already crippled, it may easily be conceived, will soon so far destroy them as to render the truss an useless burden upon the beam. This is a fact that has been long known to many of our best carpenters, and which has caused them to seek for a remedy in iron trusses; but this method is quite as bad as the former, unless there be an iron tie as an abutment to the truss, for the failure of a truss is occasioned by the enormous compression applied upon a small surface of timber at the abutments.

142. The above remarks are further confirmed by some experiments that have been made by Mr. Barlow, of the Royal Military Academy, at Woolwich, the results of which are shown in the following table.

| Description. | Length of bearing. | | Weight. | Deflexion produced by the weight. |
|---|---|---|---|---|
| | feet. | inches. | pounds. | |
| Two trusses meeting against a king bolt in the centre, with plate bolts at the abutments .............. | 4 | 2 | 600 | 0·87 |
| Piece of the same size, without trusses | 4 | 2 | 600 | 1·00 |
| Three trusses, with two queen bolts with plate bolts at the abutments .. | 5 | 8 | 500 | 2·25 |
| Piece of the same size, without trusses | 5 | 8 | 500 | 1·55 |

The pieces were trussed in the manner described by Mr. Nicholson, in his Carpenter's Guide, Plate XXXIX.; the depth of the pieces 2 inches, and the breadth 1¾ inches. In the experiment with the girder having a king bolt and two truss pieces, there appears to be a slight advantage in trussing; but in the one in three lengths, trussing appears to have had no effect, it being much weaker than the untrussed piece *.

The methods of trussing proposed by Smith †, Price ‡, and Langley §, are still worse; some in principle, others in the materials. The attempt to make a solid beam stronger in the same bulk, without using a stronger material than the beam itself is made of, is ridiculous; yet such has been the aim of most of these writers.

Though the usual mode of trussing girders cannot be relied upon, nor, indeed, any other timber truss that is made within the depth of the beam; yet, by adding to the depth, there are several methods that may be applied with success in extending the bearing of timber girders. But where the depth is limited, and the bearing considerable, iron must be employed, and the best mode of doing this would be to make the

* See Mr. Barlow's Essay on the Strength and Stress of Timber, p. 196.

† Smith's Carpenter's Companion.

‡ British Carpenter, Plate P.

§ Langley's Builder's Complete Assistant, plate lii. 4th edit.

girders of cast iron, each in one piece, if the bearing should not be too long for a casting, and in two pieces if it should be too long. These cast iron girders are simple, and cheaper than any kind of iron framing of the same strength; that is, when they are properly contrived, so as to make the most of the material.

But it often happens that large founderies are not near, and consequently iron girders would be very expensive; and at any rate it is not proper to omit showing how they may be done without, when there is the means of increasing the depth of the floor, which may generally be done without inconvenience.

143. The principle of constructing girders of any depth is the same as that of building beams, and when properly conducted is as strong as any truss can be made of the same depth.

The most simple method consists in bolting two pieces together, with keys between, to prevent the parts sliding upon each other. The joints should be at or near the middle of the depth. *Fig.* 42, *Plate* IV. shows a beam put together in this manner. The thickness of all the keys added together should be somewhat greater than one-third more than the whole depth of the girder; and, if they be made of hard wood, the breadth should be about twice the thickness.

144. *Fig.* 43 is another girder of the same construction, except that it is held together with hoops instead of bolts. The girder being cut so as to be smaller towards the ends, would admit of these hoops being driven on till they would be perfectly tight, and would make a very firm and simple connection.

145. In *fig.* 44 the parts are tabled or indented together instead of being keyed, and a king bolt is added to tighten the joints; the upper part of the girder being in two pieces. The depth of all the indents added together should not be less than two-thirds of the whole depth of the girder*.

146. Another method of constructing a girder consists in bending a piece into a curve, and securing it from springing back by bolts or straps. A girder constructed in this manner is shown by *fig.* 45. Mr. Smeaton has adopted a similar method of strengthening the beam of a steam engine†, and the additional stiffness gained by bending beams in this manner is very considerable. The pieces should be well bolted, or strapped, to prevent any sliding of the parts. In this manner a beam might be built of any depth that is necessary in the erection of buildings, and by breaking the joints of any length that is likely to be needed in the construction of floors.

The thickness of the bent pieces may be about one-fiftieth part of the bearing, and as many of them should be added as will increase the depth to that proposed, unless the

* A girder similar to this is described by Mathurin Jousse, in his Art de la Charpenterie.

† Rees's Cyclopædia, art. Steam Engine, plate i. Girders constructed in this manner have also been proposed by Rondelet, L'Art de Bâtir, tome iv. p. 145.

whole depth of the curved pieces exceeds half the depth of the girder; and in that case straight pieces should be added to the under side, so as to make the whole depth of the straight parts exceed the depth of the curved parts. When pieces cannot be got sufficiently long for the girder, care should be taken to have no joints near the middle of the length in the lower half of the girder.

*Fig.* 45 shows a girder for a 40 feet bearing, with the lower half scarfed at *a*, and a plain but joint in the curved part at *b*.

147. In the construction of floors it would be a great advantage to make each girder only half the breadth given by the rule, and to place them only 5 feet apart; to bridge the upper or floor joists over the girders, and notch the ceiling joists to the under side of them; and to omit the binding joists. There would be a great increase of strength and stiffness by adopting this method; and in point of economy, it is decidedly preferable; only it requires a much greater depth of flooring.

148. As the strain is always greatest at the middle of the length of a girder, it would be well to avoid making mortises there, if possible, either for binding joists or any other purpose; and the most straight grained part of the beam should be put to the under side.

Also, timber girders should not be built into the wall, but an open space should be left round their ends, either by laying a flat stone over them, or by turning an arch to carry the wall above.

Girders should be laid from 9 to 12 inches into the wall, according to the bearing.

### *Binding Joists.*

149. The depth of a binding joist is generally determined by the depth of the floor, but this is not always the case. Therefore the rules must be given for two cases.

*Case* 1. To find the depth of a binding joist, the length and breadth being given.

RULE. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 3·42 for fir, or by 3·53 for oak, will give the depth in inches.

150. *Case* 2. To find the breadth, when the depth and length are given.

RULE. Divide the square of the length in feet, by the cube of the depth in inches; and multiply the quotient by 40 for fir, or by 44 for oak, which will give the breadth in inches.

These rules suppose the distance apart to be 6 feet; if the distance apart be greater or less than 6 feet, the breadth given by the rule must be increased or diminished in proportion. The breadth of the binding joists next the wall may be two-thirds of the

breadth of the others; but in general they are made the same breadth, or such as are defective are selected for that purpose.

151. The binding joists may be from 4 to 6 feet apart, but should not exceed 6 feet; and about 6 inches bearing on the wall is sufficient.

The manner of framing binding joists into girders is shown by *fig.* 46; and in fitting them great care should be taken that both the bearing parts, *a* and *b*, should fit to the corresponding parts of the mortise. This is the most important part of fitting in a binding joist, yet is often the least attended to. The tenon should be about one-sixth of the depth, and at one-third of the depth from the lower side.

152. Binding joists that have only to carry a ceiling may have their scantlings found by the same rule as for ceiling joists (see art. 154;) except that the quotient must be multiplied by 1·2 instead of 0·64 for fir, and by 1·25 instead of 0·67 for oak joists.

### *Bridging Joists.*

153. The rule for bridging joists is the same as that for single joisting (see art. 137.) They seldom need be more than two inches in thickness, except for ground floors, where they are laid upon sleepers; in which case, the depth may be found to a breadth of two inches, and an inch may be added to the breadth, on account of the situation; as when proper care is not taken to drain and ventilate the under side of a ground floor, the joists are subject to very rapid decay. It is a good practice to strew smiths' ashes, or even common ashes, under such floors, to prevent the growth of fungi. The ashes and scoriæ from a foundery, or any ashes that contain much iron, are the best. Mr. Batson found this an effectual remedy for the dry rot. He filled a space below the floor of two feet in depth, with anchor smiths' ashes, and also charred the sleepers*. (See Sect. X. art. 342.)

### *Ceiling Joists.*

154. Ceiling joists require to be no thicker than is necessary to nail the laths to; two inches is quite sufficient for that purpose.

To find the depth of a ceiling joist, when the length of bearing and breadth are given.

RULE. Divide the length in feet by the cube root of the breadth in inches; and multiply the quotient by 0·64 for fir, or by 0·67 for oak, which will give the depth in inches required.

* Transactions of the Society of Arts, vol. xii. p. 265.

*Example.* Let the bearing be 6 feet, and the breadth 2 inches; to find the depth of a ceiling joist of fir.

The cube root of 2 is nearly 1·26; and the length, 6 feet, divided by this number, that is, $\frac{6}{1 \cdot 26} = 4 \cdot 76$; which being multiplied by the decimal 0·64, gives 3 inches, the depth required.

155. If two inches be fixed upon for the breadth, the rule for ceiling joists of fir becomes very easy; for then half the length in feet is the depth in inches: that is, if the length of bearing be 10 feet, the depth of the joist should be 5 inches. The distance apart in the clear is generally from 10 to 12 inches, according to the length of the laths.

It is better to notch ceiling joists to the under side of the binding joists, and nail them, than to mortise and chase them in; because it requires less labour, it does not weaken the binding joists, and the ceiling stands better. Oak is not so good a material for ceiling joists as fir, because it is more subject to warp; particularly if it be not well seasoned.

*General Observations respecting Floors.*

156. Girders should never be laid over openings, such as doors or windows, if it be possible to avoid it; and when it is absolutely necessary to lay them so, the wall-plates, or templets, must be made strong, and long enough to throw the weight upon the piers. It is, however, a bad practice to lay girders very obliquely across the rooms; and it is better to put a strong piece as a wall-plate.

In the bearings of floors the caution of Vitruvius must be attended to; that is, when the ends of the joists are supported by external walls of considerable height, the middle part of the joist should never rest upon a partition wall that does not go higher than the floor*; otherwise the unequal settlement of the walls will cause the floor to be unlevel, and most likely fracture the cornices.

157. Wall-plates and templets should be made stronger as the span becomes longer; the following proportions may serve for general purposes:

| | inches. | | inches. |
|---|---|---|---|
| For a 20 feet bearing, wall-plates | 4½ | by | 3 |
| 30 .................... | 6 | by | 4 |
| 40 .................... | 7½ | by | 5 |

158. Floors should always be kept about three-fourths of an inch higher in the middle than at the sides of a room when first framed; and also the ceiling joists should be

* Vitruvius, lib. vii. cap. 1.

fixed about three-fourths of an inch in 20 feet higher in the middle than at the sides of the room; as all floors, however well constructed, will settle in some degree.

In laying the flooring, the boards should always be made to rise a little under the doorways, in order that the doors may shut close without dragging; and at the same time it assists in making them clear the carpet.

The following observations, from Evelyn's Silva, are worthy of notice: "To prevent all possible accidents, when you lay floors, let the joints be shot, fitted, and tacked down only the first year, nailing them for good and all the next; and by this means they will lie staunch, close, and without shrinking in the least, as if they were all of one piece: and upon this occasion I am to add an observation that may prove of no small use to builders, that if one take up deal boards that may have lain in the floor an hundred years, and shoot them again, they will certainly shrink (toties quoties) without the former method*."

*Floors constructed with Short Timbers.*

159. There are many curious methods of constructing floors with short timbers, which cannot be passed over without notice, and yet are scarcely worthy of it; because they are seldom applied, as long timber is always to be had. To those, however, who are more inclined to pursue curious than useful information, the following notices respecting such floors may be acceptable.

Let ABCD, *fig.* 47, *Plate* IV. represent the plan of a room, and let four joists be mortised and tenoned together at *a*, *b*, *c*, and *d*, in the form shown in the figure; then it is evident that these joists will mutually support one another. Each joist being supported at one end by the wall, and at the other by the middle of the next joist. This is one of the most simple forms, and will sufficiently explain the principle of constructing a floor of shorter timbers than will reach across the room.

The same thing may be done by mortising and tenoning the joists together in the form represented in *fig.* 48; and various other forms will readily suggest themselves, the manner being once understood.

A design for this kind of floor was given by Serlio†; and the celebrated mathematician Dr. Wallis has entered very fully into the investigation of the strength and disposition of these floors, in the first volume of his mathematical works. The researches of Dr. Wallis have been reprinted in Nicholson's Architectural Dictionary, art. Naked Flooring. The Dutch manner of framing these floors is given in Krafft's Recueil de Char-

* Evelyn's Silva, Dr. Hunter's edit. vol. ii. p. 217.

† Tutte L'Opera d'Architettura di Serlio da Scamozzi Vineg. 1600, lib. i.

pente, part ii.; and several forms are exhibited in Rondelet's L'Art de Bâtir, tome iv. p. 149, &c.

160. Perhaps the most singular floor that ever was constructed on a large scale is one that was executed in Amsterdam, for a room 60 feet square, which has no joists whatever. There are very strong wall-plates on each side of the room, firmly secured with iron straps at the angles, and rebated to receive the flooring. The flooring consists of three thicknesses of $1\frac{1}{2}$ inch boards. The first thickness is laid diagonally across the opening, the ends resting in the rebates of the wall-plates; and rising about $2\frac{1}{2}$ inches higher in the middle than at the sides of the room. The second thickness of boards is laid diagonally, but the direction is the reverse of the first thickness; and the two thicknesses are well nailed together. The boards of the third thickness are laid parallel to one of the sides of the room, and form the upper side of the floor, being also well nailed to the boards below. All the boards are grooved and tongued together, and form a solid floor $4\frac{1}{2}$ inches in thickness *. This example shows how much may be accomplished by a well disposed bond, and firm connection of parts. This floor partakes of the nature of a thin plate supported all round the edges; the strengths of plates supported in this manner are directly as the squares of their thicknesses, and they are equally strong to support a weight in the middle, whatever the extent of bearing may be; but when the load is uniformly distributed, the strength is inversely as the area of the space it covers †.

* Rondelet's L'Art de Bâtir, tome iv. p. 154.

† Emerson's Mechanics, 4to. sect. viii. prop. 73, cor. 5.

# SECTION IV.

## OF THE CONSTRUCTION OF ROOFS.

161. A ROOF is intended to cover and protect a building from the effects of the weather, and also to bind and give strength and firmness to the fabric. To effect these purposes it should neither be too heavy nor too light, but of a just proportion in all its parts to the magnitude of the building. Mr. Ware observes, that in practice roofs are generally made too heavy; and that he will do a most acceptable service to his profession, who shall show how to retrench and execute the same roof with the smallest quantity of timber; he will by this take an unnecessary load off the walls, and a large and useless expense from the owner*."

The timber roofs of our ancestors, in the styles of building called Norman and Gothic, were generally made without horizontal ties at the feet of the rafters, and were intended to be supported by the walls as an arch is supported by its abutments. The heavy walls they were in the habit of erecting in the Norman style, and the skilful disposition of buttresses in the Gothic, rendering ties unnecessary; besides, a tie beam would have been wholly incompatible with their mode of finishing the interior of a building.

Their principles of construction bear a nearer analogy to masonry than to modern carpentry. It is true they sometimes erred in placing too great an oblique pressure against the walls, but in general we have more to admire than condemn in those celebrated buildings. The fashion of timber framed roofs originated about the reign of Edward III. as applied to great halls. They became common about 1400, and spans of considerable extent were roofed in a most judicious manner. The timber roof of the Gothic architects was generally executed in oak, and ornamented with bold and graceful mouldings, having richly carved ornaments at the joinings. The most elaborate specimens are the halls at Christ Church, Oxford, and Hampton Court; that at Trinity College, Cambridge, is somewhat inferior: each of these is 40 feet span †. The span of the roof of Westminster Hall is 66 feet ‡.

In the old Gothic buildings the roof is always of a high pitch; its outline forms a striking feature, and in general is in graceful proportion with the magnitude of the building: sometimes, however, it presents too extensive a plain surface, of which we have a notable instance in the roof of Westminster Hall. A high roof is in perfect unison with the aspiring and pyramidal character of Gothic architecture; but in the opposite, though not less beautiful style of the Greeks, it becomes a less conspicuous

* Ware's Body of Architecture. † Dallaway's Observations on English Architecture, p. 188. ‡ Idem, p. 189.

object: indeed, many of the Grecian buildings were never intended to be roofed at all. Yet when a roof was necessary it was not attempted to be hidden, but constituted one of the most ornamental parts of the building. Of timber roofs we have no examples in Grecian buildings; but the beautiful stone roof of the Octagon Tower of Andronicus Cyrrhestes*, and that of the Choragic Monument of Lysicrates†, are sufficient to show that they were more inclined to ornament than hide this essential part of a building.

162. In carpentry, the term *Roof* is applied to the framing of timber which supports the covering of a building. The *Pitch* of a roof, or the angle which its inclined side forms with the horizon, is varied according to the climate and the nature of the covering. The inhabitants of cold countries make their roofs very high, while those of warm countries, where it seldom rains or snows, make their roofs nearly flat. But even in the same climate the pitch of the roof has been subject to many variations. Formerly the roofs were made very high, perhaps with the notion that the snow would slide off easier; but where there are parapets, a high roof is attended with bad effects, as the snow slips down and stops the gutters, and an overflow of water is the consequence; besides, the water in heavy rains descends with such velocity that the pipes cannot convey it away soon enough to prevent the gutters being overflown. In high roofs the action of the wind is one of the most considerable forces they have to sustain, and it appears to have been with a view of lessening their height that the Mansard or curb roof was invented. This form of roof has however been in a great measure abandoned, being now adopted in town houses only; and were it not for the absurd restrictions in the Building Act, they would very soon be wholly laid aside. The quantity of room lost by a curb roof, the difficulty of freeing the gutters from snow, and the ungraceful effect of the roof itself, are objections that few would encounter to save the small difference between the expense of this and a common roof, especially now that experience has proved that roofs may be made of a much less height than our ancestors were in the habit of making them.

163. The height of roofs at the present time is very rarely above one-third of the span, and should never be less than one-sixth. The most usual pitch for slates is that when the height is one-fourth of the span, or when the angle with the horizon is $26\frac{1}{2}$ degrees.

The pediments of the Greek temples make an angle of from 12 to 16 degrees with the horizon; the latter corresponds nearly with one-seventh of the span. The pediments of the Roman buildings vary from 23 to 24 degrees: 24 degrees is nearly two-ninths of the span.

The kinds of covering used for timber roofs are copper, lead, iron, tinned iron, slates

* Stewart's Athens, vol. i. p. 13. † Idem, vol. i. p. 27.

of different kinds, tiles, shingles*, reeds, straw, and heath. Taking the angle for slates to be $26\frac{1}{2}$ degrees, the following table will show the degree of inclination that may be given for other materials.

| Kind of covering. | Inclination to the horizon in degrees. | | Height of roof in parts of span. | Weight upon a square of roofing. |
|---|---|---|---|---|
| | degrees. | minutes. | | |
| Copper or lead ............ | 3 | 50 | $\frac{1}{30}$ | copper 100; lead 700 |
| Slates, large ............... | 22 | 0 | $\frac{1}{5}$ | 1120 |
| Ditto, ordinary ............ | 26 | 33 | $\frac{1}{4}$ | from 900 to 500 |
| Stone slate ............... | 29 | 41 | $\frac{2}{7}$ | 2380 |
| Plain tiles ................ | 29 | 41 | $\frac{2}{7}$ | 1780 |
| Pan-tiles .................. | 24 | 0 | $\frac{2}{9}$ | 650 |
| Thatch of straw, reeds, or heath | 45 | | $\frac{1}{2}$ | |

*Of the Forms of Roofs for different Spans.*

164. A roof for a span of from 20 to 30 feet may have a truss of the form shown in *Plate* V. *fig*. 49. Within the limits above stated the purlins do not become too wide apart, nor the points of support for the tie beam; and in the table, No. 5, at the end of the volume, the scantlings of the timbers are given according to the length and bearing of the different parts. The figure (49) is drawn with a parapet on one side and eaves on the other side.

165. For spans exceeding 30 feet, and under 45 feet, the truss exhibited in *Plate* V. *fig*. 50, is extremely well adapted; each purlin is supported, consequently there are no cross strains on the principal rafters; and the points of support divide the tie beam into three comparatively short bearings. The scantlings may be had from the table, No. 6, at the end of the volume.

The sagging which usually takes place from the shrinking of the heads of the queen posts may be avoided by letting the end of the principal rafter abut against the end of the straining beam S; and notching pieces and bolting them together in pairs at each joint. The side marked D of the figure is supposed to be done in this manner. This is further illustrated in Sect. IX. See art. 306. The same method is applicable to any other roof, therefore it appeared better to explain it under the head of Joints than under any particular design.

166. When the span exceeds 45 feet, and is not more than 60 feet, the truss shown

* Shingles are now very little used in this country, though they appear to have been much used formerly. See Neve's Builder's Dictionary, art. Shingle; Britton's Archit. Antiq. vol. ii. p. 79.

in *Plate* VI. *fig*. 51, is sufficiently strong for the purpose, and leaves a considerable degree of free space in the middle. For this span the tie beam will most likely require to be scarfed, and as the bearing of that portion of the tie beam between *a* and *b* is short, the scarf should be made there. The middle part of the tie beam may be made stronger by bolting the straining sill *s* to it. The scantlings may be got from the table, No. 7, at the end of the volume; and the principles of scarfing and joints are detailed in Sect. IX.

167. A truss for a roof from 75 to 90 feet span is shown by *fig*. 52, *Plate* VI. In this truss the straining sill *s* should be tabled or keyed, and bolted to the tie beam in the manner that has already been proposed for increasing the depth of girders (see Sect. III. art. 143.) This truss nearly resembles the roof of the Birmingham Theatre*.

168. By omitting, or rather reducing, the upper part of the truss in *fig*. 52 to the same form as that in *fig*. 51, the truss would answer for a bearing of from 60 to 75 feet. The scantlings may be had from the table, No. 8, at the end of the volume.

But when the span is so very wide, unless the building be of a proportional height, the roof exhibits such an immense mass of plain surface, that it destroys the architectural effect of the building; besides, it is difficult to light the large space in the roof in any way that would not be objectionable, on account of the external appearance.

169. To avoid a large expanse of roof, the truss may be of the form shown in *Plate* VII. *fig*. 53, from Price's British Carpenter. A roof of this form is called an M roof. This roof would do for a span of from 55 to 65 feet; but it would be better to make the top flat, and cover it with lead, and adopt the truss represented in *Plate* VI. *fig*. 52, as the space gained in the roof would amply repay the expense of the lead flat. The scantlings of the M roof may be got from the table, No. 9, at the end of the volume.

170. In spans that exceed 65 feet the truss that was adopted in the construction of Drury Lane Theatre, in 1793, is, in respect to form, perhaps one of the best that can be devised of its kind†. *Plate* VII. *fig*. 54, shows a roof on the same principle, of which the scantlings may be obtained from the table, No. 10, at the end of the volume. One part of the principal truss is shown with a queen post, the other with suspending pieces, as described in art. 306, Sect. IX. The middle part of the principal tie beam is supposed to be built as a girder.

171. There is a considerable degree of difficulty in executing a roof when there are a great number of joints, and the timbers of large dimensions; and the shrinkage of the king or queen posts often produces considerable derangements in the truss. It is

* The roof of the Birmingham Theatre is described, with the scantlings of the timbers, in Mr. Nicholson's Carpenter's Assistant, p. 61, plate lxxiii. 2nd edit.

† A description of the roof of Drury Lane Theatre is given in Nicholson's Carpenter's Assistant, p. 60. plate lxxi.

obvious, that to make principal rafters in a continued series of pieces abutting end to end against one another would remedy these defects. These pieces would then form a kind of curve, and, according to the degree of neatness required, might be made regular, or left with projecting angles, as is shown by *fig.* 55, *Plate* VIII. These pieces might either be bolted, or mortised and put together with wooden keys, as represented in *fig.* 56. The length of the pieces would be determined by the form of the curve; crooked timber would be preferable for the ribs where it could be procured, as the joints should be as few as possible, and they should be crossed, like the joints in stone-work.

*Plate* VIII. *fig.* 57, shows a roof constructed in this manner. Each of the supports for the tie beam marked S, S, &c. consists of two pieces, one put on each side of the rib, and notched both to the rib and to the tie beam. The pieces are bolted together, as is shown by a section to a larger scale, through one of these pairs of suspending pieces, in *fig.* 58. This mode of construction admits of a much firmer connection with the tie beam than is procured by the ordinary mode, and the number of suspending pieces may be increased at pleasure. The best situation for the suspending pieces is at the joints of the curved rib.

The weight of the roof being very nearly uniformly distributed, the form of the curved rib should be a parabola (see Sect. I. art. 57;) and as this curve is easily described with sufficient accuracy for this purpose, it is best to adopt it; because, in that case, the strain from the weight of the roof and ceiling will have no tendency whatever to derange the form of the rib; and its depth will always be sufficient to withstand any partial force to which a roof is ever likely to be exposed. Consequently, when the rib is of a parabolic form, diagonal braces will be unnecessary; nevertheless they may be added if thought necessary, as is shown by the lines in the figure. But it may be remarked, that these braces will increase the strength to resist any partial strain in a very considerable degree.

To construct the parabola, let AB, *fig.* 59, be drawn for the upper side of the tie beam, and AC, CB, for the under side of the common or small rafters. Then divide AC and CB each into the same number of equal parts (an even number is to be preferred;) and join the points 1 and 1, 2 and 2, &c.; then the curve formed by these intersecting lines will be the parabola required.

But it will be found that this curve scarcely differs from a circular arc that rises half the height of the roof; therefore either may be used.

If a lantern or any other structure be to be raised on the top, a hyperbolic curve should be adopted; which admits of a considerable increase of pressure at the crown*.

The scantlings of the curved ribs are given in table, No. 12, at the end of the volume.

* The most simple method of describing this curve is given by Mr. Nicholson, in his Carpenter's Guide, p. 11: which work I suppose every carpenter to be in possession of.

The tie beam will require to be scarfed for large spans, and would be best made in two thicknesses, and joined so that the scarfs should not be opposite one another.

172. Smaller roofs might be constructed in a similar manner, at a comparatively small expense. But in these, instead of forming the rib of short pieces, it might be bent by a method somewhat similar to that proposed by Mr. Hookey for bending ship timber*.

If the depth of a piece of timber does not exceed about a hundred and twentieth part of its length, it may be bent into a curve that will rise about one-eighth of the span without impairing its elastic force. And if two such pieces be laid one upon the other, and then bent together by means of a rope fixed at the ends, they may be easily bent to the form of the required curve, by twisting the rope as a stone sawyer tightens his saw, or as a common bow-saw is tightened. The pieces may then be bolted together; and if this operation be performed in a workman-like manner, the pieces will spring very little when the rope is gently slacked; and it is advisable to do it gradually, that the parts may take their proper bearing without crippling.

Otherwise, a piece of about one-sixtieth part of the span in thickness may be sawn along the middle of its depth, with a thin saw, from each end towards the middle of the length, leaving a part of about 8 feet in the middle of the length uncut. The pieces may then be bent to the proper curve, and bolted as before.

In either case the rise of the ribs should be half the height of the roof; and they should be bent about one-fourth more, to allow for the springing back when the rope is taken off. A roof of this kind for a 30 feet span is shown by *Plate* VIII. *fig*. 60. The suspending pieces are notched on each side, in pairs, and bolted or strapped together, as shown by *fig*. 58.

The advantages of this roof consist in the small number of joints in the truss, in being able to support the tie beam at any number of points, in admitting of a firm and simple connection with the tie beam, and in avoiding the ill effects attending the shrinking of king or queen posts. The scantlings are given in table, No. 11, at the end of the volume.

173. In the construction of modern roofs a continued tie at the foot of the rafters is always necessary, though sometimes it has been omitted, for in general the lightness of the walls renders them incapable of sustaining much lateral pressure; and this pressure is entirely removed by a tie beam.

As leaving out the tie beam gains only a very small space in height, and which might generally be obtained without injury to the external effect of the building, by raising the walls a little higher, I will endeavour to show the defects of roofs without tie beams.

* Transactions of the Society of Arts, vol. xxxii. p. 95.

In the first place, let *fig*. 61, *Plate* IX. represent a roof with a collar beam C*c*, the whole weight of such a roof is sustained by the parts of the rafters AC, and B*c*, and when the roof has the weight of the covering upon it, it will settle in proportion to this weight, in consequence of the lower parts of the rafters bending at C, *c*, which will press out the walls. The reader who has thoroughly considered the effect of weight in producing flexure, will readily see that a pressure against the walls cannot be avoided in this construction, though it may be lessened, by making the rafters very strong at the lower part. I have often observed failures from adopting this form for a roof.

174. In wider spans another mode of construction has been employed, which, though better, is not a good one, from the powerful strains that are excited in it by the oblique disposition of the beams. To show the nature of these strains, I have taken *fig*. 62 from Mr. Price's work*, who has said much in praise of it, without being capable of investigating its construction according to the principles of mechanics. The essential parts of this roof are contained in *fig*. 8, *Plate* I.; and by comparing the strains produced by the weight in that figure, with the strains when CA is in a horizontal position, it will be found the strains are more than doubled by the oblique position of CA. Returning again to the section of the roof in *Plate* IX. Let the vertical line *a*E be drawn, *fig*. 62, and let *a b* upon this line represent the weight of half the roof; also draw *c b* parallel to AC, and *c a* parallel to AD. Then the weight and pressures will be measured by *ab*, *bc*, and *ac*. But if there had been a tie beam AB, the pressures produced by the same weight would have been only *bd* and *ad*; hence it appears, that they are nearly doubled, while the space gained in the middle in height amounts only to about one-ninth of the span. To gain this small advantage, we encounter the difficulty of making a firm connection of the ties at C, with the certainty of a considerable degree of settlement from the number of the joints, and the magnitude of the strains. It also must be remembered, that the same degree of settlement will produce a greater effect in thrusting out the walls in proportion as CE is greater. Having thus pointed out the defects of this kind of roof, I shall leave the reader to judge for himself on the propriety of adopting it.

175. The centre aisle of churches being often higher than the side ones, the same effect as when the tie continues through may be produced by connecting the lower beams, by means of braces, to the upper one, so that the whole may be as a single beam. To illustrate this principle I have drawn the roof in *fig*. 63, which is for a church similar to St. Martin's, in London. Here the lower ties, B, B′, are so connected to the principal tie beam AA′, by means of the braces *b*, *b*′, that the foot of the principal rafters P, P′, cannot spread without stretching AA′. The iron rods, *a*, *a*′, perform the office of king

* British Carpenter, plate K, fig. L.

posts to the ties B, B′; and are better than timber, because the shrinkage of timber ones would be particularly objectionable in that situation. The oblique positions of $dd'$ will render them effectual in opposing the spread of the rafters.

*Fig.* 64, *Plate* IX. is a sketch of the roof of Westminster School, from Smith's Specimens of Ancient Carpentry*. It shows the most usual form of the roofs of Gothic halls, as they differ more in the tracery and ornaments than in the essential parts of the framing. The timbers are so disposed as to throw the pressures a considerable way down the walls, and at the same time nearly in a vertical direction. Indeed, considering the effect that was intended to be produced, the arrangement of the parts is worthy of much praise.

### *On Proportioning the Parts of Roofs.*

176. The proportions of the timbers depend so much on the design of the framing of a roof, that it would be impossible to furnish rules that would apply directly to all cases; nevertheless, by considering a few cases, the method that may be adopted will be seen, and consequently may be applied to designs made on other principles than those already shown. In roofs, as in floors, I have taken the constant number from a comparison of roofs already executed, and known to stand.

### *Of King Posts (sometimes called Crown Posts.)*

177. The king post is intended to support the ceiling, and, by means of the braces, to support part of the weight of the roof; and is marked K in the roofs, *fig.* 49, 52, and 54, *Plates* V. VI. and VII. The weight suspended by the king post will be proportional to the span of the roof; therefore, to find the scantling,

RULE. Multiply the length of the post in feet, by the span in feet. Then multiply this product by the decimal 0·12 for fir, or by 0·13 for oak, which will give the area of the king post in inches; and divide this area by the breadth, and it will give the thickness: or by the thickness for the breadth.

* Plate viii. Smith's specimens would have been valuable if they had been accompanied with dimensions, and a short description of each.

*Queen Posts and Suspending Pieces.*

178. Queen posts and suspending pieces are strained in a similar manner to king posts, but the load upon them is only proportional to that part of the length of the tie beam suspended by each suspending piece or queen post. In queen posts the part suspended by each is generally half the span.

RULE. Multiply the length in feet, of the queen post or suspending piece, by that part of the length of the tie beam it supports, also in feet. This product multiplied by the decimal 0·27 for fir, or by 0·32 for oak, will give the area of the post in inches; and divide this area by the thickness will give the breadth.

*Example.* In the roof, *fig.* 50, *Plate* V. each queen post, Q, supports one-third of the tie beam, or 13·3 feet of it, and the length of the queen post is 6 feet; therefore $13{\cdot}3 \times 6 \times 0{\cdot}27 = 21{\cdot}546$, the area in the shaft in inches. If the thickness of the truss be six inches, then $\frac{21{\cdot}546}{6} = 3{\cdot}6$ nearly, and the queen post should be 6 inches by 3·6 inches. I have put it 6 by 4 in the table, No. 6.

These rules give the scantling in the smallest part of the pieces, and in order to avoid the bad effects arising from the shrinking of the king or queen posts, the heads must be kept as small as possible, and the timber should be well seasoned. Hard oak makes the best, because it will be least compressed by the ends of the principal rafters.

179. It has been proposed to let the ends of the principal rafters abut against each other, and to suspend the king post by straps of iron; but a piece of good carpentry should depend as little on straps as possible, and it would be better, and less expensive, to make a king or queen post wholly of cast iron, than to depend on wrought iron. The breadth of a cast-iron king or queen post should be about one-fourth of an oak one, to be equally as strong. By a method described in Sect. IX. art. 306, *fig.* 150 and 151, *Plate* XXIII. the rafters abut against each other, and the tie beam is suspended by pieces bolted on each side; which is perhaps the best in use.

180. The common method of forming the joint between the principal rafter and king post is shown by *fig.* 143, *Plate* XXII.; but it is obvious that when the roof settles, unless it be provided for the change, the whole bearing will be on the upper angles of the joints, as at *a*, and these sharp angles will indent into the king post, or become bruised in proportion to the degree of settling, and of course increase it. And as all roofs will settle more or less, the carpenter will see how important it is to make the joints bear on the opposite corner when first fitted. To remedy this defect, I would propose to make the joint in the form of a circular arc, in order that the pressure

on every part may be equal, whatever degree of settling may take place. A joint of this kind is shown by *fig.* 149; and A and D show the parts separated. The centre for describing the arc should be in the middle of the depth of the rafter, and should be as near the end as possible, so as not to cut too much into the king post. See Sect. IX. art. 304 and 305.

### *Tie Beams.*

181. A tie beam is affected by two strains, the one in the direction of the length from the thrust of the principal rafters, the other is a cross strain from the weight of the ceiling. In estimating the strength, the thrust of the rafters need not be considered, because the beam is always abundantly strong to resist this strain; and when a beam is strained in the direction of the length, it rather increases the strength to resist a cross strain. Therefore the pressure or the weight supported by the tie beam will be proportional to the length of the longest part of it that is unsupported. But there are two cases, one where the weight is merely the weight of the ceiling; the other where there are rooms in the roof.

*Case* 1. To find the scantling of a tie beam that has only to support a ceiling, the length of the longest unsupported part being given.

RULE. Divide the length of the longest unsupported part by the cube root of the breadth; and the quotient multiplied by 1·47 will be the depth required for fir, in inches; or multiply by 1·52, which will give the depth for oak, in inches.

182. *Case* 2. In the case where there are rooms above the tie beam, the rule is the same as that for girders. See Sect. III. art. 138 and 139.

*Example to Case* 1. The length of the longest unsupported part of the tie beam in the roof, *fig.* 53, *Plate* VII. is 17 feet; and let the thickness of the truss be 9 inches. Then the cube root of 9 is 2·08 very nearly; therefore, $\frac{17 \times 1{\cdot}47}{2{\cdot}08} = 12$ inches, the depth required.

183. Tie beams are often unnecessarily cut to pieces with mortises, where the king or queen posts join them, it is much better to make very short tenons to the lower end of these posts, and to support the beam by means of straps. The best method of cocking or cogging the tie beam upon the wall plate is shown by *fig.* 65, *Plate* IX.

Sometimes blocks are placed under the ends of tie beams, for the purpose of adding to the security of the roof if the ends of the tie beams should decay. The roof of the Theatre d'Argentina, and that of the Basilica of St. Paul, have blocks of this

kind (see *Plate* X.) The present roof of Covent Garden Theatre, and that of Drury Lane Theatre, are also done in this manner; as well as several other modern roofs.

In respect to the use of these blocks as a security in case of decay, it can only be from affording a greater quantity of matter for the causes of decay to act upon, and is as likely to accelerate as to retard its progress. And by adding to the depth of timber at the points of support, the settlement from shrinkage will become considerable. Also, whether the blocks be firmly connected to the tie beam or not, by raising the middle part of the tie beam above the real points of support, a lateral pressure equivalent to that of a beam, cambered in the same degree, will be exerted against the walls.

If the ends of the tie beams be left with a perfectly free space round them, so that there would be nothing to retain any moisture in contact with them, there would be little to apprehend from decay. And if a further security should be thought necessary, cast-iron plates might be used instead of wooden blocks.

It is a common practice in framing roofs to force the tie beam to a certain degree of camber, which appears to have been introduced under the idea that a cambered beam partakes of the nature of an arch; this, as has been justly observed by a late writer*, is one of the fallacies which it is the business of the mathematical theory of carpentry to dispel. It is obvious that when a cambered beam settles it has a tendency to thrust out the walls instead of being a bond to tie them together. The Gothic builders sometimes laid naturally crooked timbers with the round side upwards for tie beams; but then their walls were capable of supporting a considerable lateral pressure. In some of the tie beams of Durham Cathedral this curvature is very considerable; but modern walls are constructed on different principles, and require all the connection a roof can be made to give them, instead of being sufficient to withstand the thrust of a cambered beam. Where there are ceiling joists it is easy to keep them a little higher in the middle of a ceiling, at the rate of about an inch in 20 feet, which prevents the settling from offending "the eye of the beholder;" and consequently accomplishes all that Mr. Price and others propose to do by cambering the tie beam.

## *Principal Rafters.*

184. In estimating the strength of principal rafters, I suppose them to be supported by struts, either at or very near to all the points where the purlins rest upon. The pressure on a principal rafter is in the direction of its length, and is in proportion to the magnitude of the roof; but this pressure does not bear the same proportion to the

* Encyclopædia Britannica, art. Carpentry, Supplement, p. 646.

weight when there is a king post, as when there are queen posts; therefore the same constant number will not answer for both cases.

*Case* 1. To find the scantling of the principal rafter when there is a king post in the middle.

RULE. Multiply the square of the length of the rafter in feet, by the span in feet; and divide the product by the cube of the thickness in inches. For fir, multiply the quotient by 0·96, which will give the depth in inches.

185. *Case* 2. To find the scantling of a principal rafter when there are two queen posts.

RULE. Multiply the square of the length of the rafter in feet, by the span in feet; and divide the product by the cube of the thickness in inches. For fir, multiply the quotient by 0·155, which will give the depth in inches.

The thickness is generally the same as the king or queen posts, and tie beam.

*Example.* The length of the principal rafter P, in *fig.* 50, *Plate* V. is 14½ feet, and the span is 40 feet, the thickness of the truss 6 inches. The square of the length is 210·25, and the cube of the thickness 216. Therefore, $\frac{210{\cdot}25 \times 40 \times 0{\cdot}155}{216} = 6$ inches nearly; that is, the principal rafters should be six inches by six inches.

186. In *fig.* 139, *Plate* XXII. is shown what is considered the best of the common methods of framing the end of the principal rafter into the tie beam; and *fig.* 142, No. 3 and 4, shows another method, with a circular abutment, which I consider to be much preferable in large roofs; and must refer the reader to the Section on Joints, Sect. IX. art. 303, for more full information; and also to art. 310, for the best method of strapping.

### *Straining Beams.*

187. A straining beam is the horizontal piece between the heads of the queen posts, and is marked S in the roof, *fig.* 50, *Plate* V.

In order that this beam may be the strongest possible, its depth should be to its thickness as 10 is to 7.

RULE. Multiply the square root of the span in feet, by the length of the straining beam in feet, and extract the square root of the product. Multiply the root by 0·9 for fir, which will give the depth in inches. To find the thickness, multiply the depth by the decimal 0·7.

C, *fig.* 144, *Plate* XXIII. shows a joint for the ends of straining beams.

### *Struts and Braces.*

188. The part of the roof that is supported by a strut or brace is easily ascertained from the design, but the effect of the load must depend on the position of the brace; when it is square from the back of the rafter, the strain upon it will be the least; and when it has the same inclination as the roof, the same strain will be thrown on the lower part of the principal rafter as is borne by the strut. But as the degree of obliqueness does not vary much, I will not attempt to include its effect in the rule for the scantling.

RULE. Multiply the square root of the length supported in feet, by the length of the brace or strut in feet; and the square root of the product multiplied by 0·8 for fir, will give the depth in inches; and the depth multiplied by the decimal 0·6, will give the breadth in inches.

*Example.* In the roof, *fig.* 50, *Plate* V. the part supported by the brace or strut B is equal to half the length of the principal rafter, or 7 feet; and the length of the brace is 6 feet. Therefore $(7^{\frac{1}{2}} \times 6)^{\frac{1}{2}} \times 0{\cdot}8 = (2{\cdot}646 \times 6)^{\frac{1}{2}} \times 0{\cdot}8 = 3{\cdot}985 \times 0{\cdot}8 = 3{\cdot}188$, the breadth; and $3{\cdot}188 \times 0{\cdot}6 = 1{\cdot}9128$, the depth; or $3\frac{1}{4}$ by 2 nearly.

If a piece intended for a brace, a principal rafter, or a straining beam, be crooked, the round side should be placed upwards.

189. I have now laid down rules for the principal parts of a truss, but in so doing I have not taken into the account the different weights of different kinds of roofing, nor the different degrees of inclination, lest the rules should become too complicated: indeed I am afraid many will suppose them too much so already; but the numerous tables of scantlings at the end of the volume will be found useful to those who are not ready at calculation; and to others the assistance of a table of squares and cubes, or a table of logarithms, will render all the rules extremely easy. It only remains now to give the rules for purlins and common rafters.

### *Purlins.*

190. The stress upon purlins is proportional to the distance they are apart; and, the weight being uniformly diffused, the stiffness is reciprocally as the cube of the length.

RULE. Multiply the cube of the length of the purlin in feet, by the distance the purlins are apart in feet; and the fourth root of the product for fir will give the depth in inches; or multiplied by 1·04, will give the depth for oak: and the depth multiplied by the decimal 0·6 will give the breadth. See Table XIV. at the end of the volume.

Purlins should always be notched upon the principal rafters, and should be put on in as long lengths as they can be conveniently got, as the strength is nearly doubled by this means. The old method of framing the purlins into the principal rafters, not only renders the purlins weaker, but also wounds the principal rafter, and consequently renders it necessary to make the rafters stronger.

There is no part of a roof so liable to fail as the purlins, indeed there are few cases where they have not sunk considerably; in some cases so much as to deform the external appearance of the roof. Weak purlins might be much strengthened by bracing them; a practice that was once very common among the builders in this country.

### *Common Rafters.*

191. Common rafters are uniformly loaded, and the breadth need not be more than from 2 inches to $2\frac{1}{2}$ inches. The depth may be found by the following rule:

RULE. Divide the length of bearing in feet, by the cube root of the breadth in inches; and the quotient multiplied by 0·72 for fir, or 0·74 for oak, will give the depth in inches.

*Example.* Let the length of bearing of a rafter of Riga fir be 7 feet, and the breadth 2 inches. The cube root of 2 is 1·26 nearly; therefore $\frac{7\times 0{\cdot}72}{1{\cdot}26}=4$ inches, the depth required. See Table XV.

Foreign fir makes the best common rafters and purlins, because it is not so subject to warp and twist with the heat of roofs in summer as oak; much however depends on the quality of the timber, as oak from old trees often stands very well.

## DESCRIPTION OF ROOFS THAT HAVE BEEN EXECUTED.

192. The roofs I have selected for description present some interesting specimens of the art of carpentry, and are well worthy of the attention of the reader. They are taken from the productions of foreigners, and may perhaps suggest some new ideas to the artist, and lead him to attain still greater excellence in his art; an art which has been carried to a high degree of perfection in this country, but is still capable of improvement.

### *Roof of the Basilica of St. Paul at Rome.*

The truss exhibited in *Plate* X. *fig.* 66, is one of the trusses of the Basilica of St. Paul at Rome, executed about 400 years ago. There is another kind of truss in

the same roof that is much older, having been executed in 816, during the pontificate of Leo III.; but the form is not so good as the one here given. These trusses are double, that is, each consists of two similar frames placed 14·9 inches apart; and these double trusses are about 10·5 feet apart. The principal rafters abut against a short king post *k*. Between the trusses a piece of timber, S, is placed, and sustained by a strong key of wood passing through it and the short king posts; this piece sustains the tie beams by means of another strong key at *a*. The tie beams are in two lengths, and scarfed together, as shown by *fig*. 67. The scarf is held together by three iron straps.

Scantlings of the Timbers.

| | inches. | | inches. |
|---|---|---|---|
| Tie beams, *t* ........ | 22·5 | by | 14·9 |
| Principal rafters, *p* ... | 21·75 | by | 14·9 |
| Auxiliary rafters, *b* ... | 13·8 | by | 13·3 |
| Straining beam, C ... | 14·9 | by | 12·8 |
| Purlins, *d* .......... | 8·5 | square, and 5 feet 7 inches apart. | |
| Common rafters .... | 5·3 | by | 4·25, and 8·5 inches apart. |

This roof is executed in fir, and the span is 78·4 feet. The common rafters are covered with strong tiles, about 12 inches by 7, forming a kind of pavement set with mortar in the joints. On this pavement a kind of plain tiles with ledges are laid, and the joints covered with crooked tiles, as is represented by *fig*. 68. From this description some notion may be formed of the load upon this roof*.

The roof is simple and strong; the method of sustaining the middle of the tie beam is ingenious; and the covering, though heavy, is well calculated to preserve a uniform temperature within the building; and a similar one might be often adopted with much advantage in our own variable climate.

### *Roof of the Theatre d'Argentina, at Rome.*

193. One of the trusses of the Theatre d'Argentina is represented in *Plate* X. *fig*. 69. The span is 80·5 feet, and the slope of the roof 24 degrees. The tie beam is in three pieces, scarfed and strapped together; and the principal rafters are each in two pieces, also scarfed and strapped together. The common rafters are from 10 to 11 inches apart, and are supported by 12 purlins on each side: these rafters support a heavy tile

* L'Art de Bâtir, tome iv. p. 170.

covering. The tie beams are supported by stirrups of iron, in a very judicious manner, which differs considerably from any other example, except that of the Theatre de l'Odéon, which is a close imitation of it, to a 77·8 feet span. The roof of the Theatre d'Argentina is executed in fir, that of the Odéon in oak; both of them have to sustain the machinery of the theatre, besides the ceilings and covering*.

There appears to be too much strength in some of the parts of this roof; but the design is extremely simple, and well adapted to the purpose.

*Roof of a Riding House at Moscow, in Russia.*

194. The largest roof that has been executed was that of the Riding House, built at Moscow, in 1790, by Paul I. Emperor of Russia. It is represented by *fig.* 70, Plate XI. The span was 235 feet, and the slope of the roof about 19 degrees. The principal support of this immense truss consisted in an arch or curved rib of timber, in three thicknesses, indented together, and strapped and bolted with iron. The principal rafters, and the tie beams, were supported by several vertical pieces notched to the curved rib; and the whole stiffened by diagonal braces. The disposition of the parts of this roof is extremely ingenious; but from the immense extent of the span, it appears that it settled so much, that it was proposed to add another curved rib in the situation shown by the dotted lines.

The external dimensions of the building were 1920 feet by 310 feet; it was lighted from the top by a lantern, and there was a gallery round the inside of the building for spectators †.

* L'Art de Bâtir, tome iv. p. 220.

† Krafft's Recueil de Charpente, part ii. No. 39; or Rondelet's L'Art de Bâtir, tome iv. pl. 116.

# SECTION V.

## OF THE CONSTRUCTION OF DOMES OR CUPOLAS.

195. A DOME or cupola is a roof, the base of which is a circle, an ellipse, or a polygon; and its vertical section a curve line, concave towards the interior. Hence domes are called circular, elliptical, or polygonal, according to the figure of the base.

The most usual form for a dome is the spherical, in which case its plan is a circle, and section a segment of a circle.

The top of a large dome is often finished with a *lantern*, which is supported by the framing of the dome.

196. The interior and exterior forms of a dome are not often alike, and in the space between, a staircase to the lantern is generally made. According to the space left between the external and internal domes, the framing must be designed. Sometimes the framing may be trussed with ties across the opening; but often the interior dome rises so high that ties cannot be got: in the latter case, the observations made on the equilibrium of domes in Sect. I. (art. 62—66) should be attended to.

Accordingly, the construction of domes may be divided into two cases; each of which it will be my next object to make a few remarks upon.

### *On the Construction of Domes which admit of Horizontal Ties.*

197. A truss for a dome where a horizontal tie can be got is shown by *fig.* 71, *Plate* XII. In this figure AA is the tie; BB posts, which may be continued to form the lantern; C, C, are continued curbs in two thicknesses, with the joints crossed and bolted together; DD, a curved rib to support the rafters. This design is calculated for a span of about 60 feet, and may be extended to 120 feet.

Two principal trusses may be placed across the opening parallel to each other, and a distance equal to the diameter of the lantern apart, as AB, CD, *fig.* 72; with a sufficient number of half trusses to reduce the bearing of the rafters to a convenient length.

Or, the two principal trusses may cross each other at right angles in the centre of the dome, the one being placed so much higher than the other as to prevent the ties interfering. This disposition is represented in *fig.* 73; and is the same as is adopted for the Dome des Invalids, at Paris, of which the external diameter is nearly 90 English feet.

As the dimensions of the parts must depend chiefly on the weight of the lantern, it is scarcely possible to fix upon any without some particular design had been described,

which would not have been satisfactory; besides being likely to mislead, as there are few cases that are similar. The dimensions of the timbers may however be easily ascertained to any particular design, from the rules and principles laid down in Sect. I. and II.

### *On the Construction of Domes without Horizontal Ties.*

198. The construction of domes without horizontal cross ties is not difficult when there is a sufficient tie round the base. The most simple method, and one which is particularly useful in small domes, is to place a series of curved ribs so that the lower ends of those ribs stand upon the curb at the base, and the upper ends meet at the top.

When the pieces are so long, and so much curved that they cannot be cut out of timber without being cut across the grain so much as to weaken them, they should be put together in thicknesses, with the joints crossed, and well nailed together: or, in very large domes, they should be bolted or keyed together. The manner of forming these ribs has been already described, as applied to roofs (see Sect. IV. art. 171.) The method of making curved ribs in thicknesses has been used in the construction of centres for arches from the earliest period of arch building; and it was first applied to the construction of domes by Philibert de Lorme*, who gives the following scantlings for different sized domes:

| | | |
|---|---|---|
| For domes of 24 feet diameter | 8 inches by | 1 inch. |
| 36 | 10 | 1½ |
| 60 | 13 | 2 |
| 90 | 13 | 2½ |
| 108 | 13 | 3 |

These ribs are formed of two thicknesses, of the scantlings given above, and are placed about two feet apart at the base. The rafters are notched upon them for receiving the boarding, and also horizontal ribs are notched on in the inside, which gives a great degree of stiffness to the whole†. *Fig.* 74 is a section of a dome constructed in this manner; and *fig.* 75 a projection of a part of the dome, with the rafters and inside ribs.

If the dome be of considerable magnitude, the curve of equilibrium should pass

* See his Nouvelles Inventions pour bien Bâtir à Petits Frais, 1561.

† Mr. Price proposes a similar mode of forming bridges and domes in his British Carpenter, p. 26 and 28.

through the middle of the depth of the ribs, particularly if a heavy lantern rests upon them. The curve in either case will be found by means of art. 64 or 65, Sect. I. Otherwise the curve must fall within the curve of equilibrium, and struts must be placed between the ribs, to prevent them bending in. Or, if it be necessary for the external appearance of the dome, that the curvature of the ribs should be without the curve of equilibrium, then an iron hoop may be put round at about one-third of the height to prevent the dome bursting outwards. This latter method was adopted in the external dome of the Church de la Salute at Venice; the outside dimensions of which are 80 feet diameter, 40·5 feet high, and the lantern 39·5 feet high; but the lantern is supported by a brick dome, which is considerably below the wooden one. The ribs of this dome are 96 in number, and each rib is in four thicknesses; the four together make 5·5 inches, so that each rib is 8·5 inches by 5·5 inches. The iron hoop is 4·5 inches wide, and half an inch in thickness, and is placed at one-third of the height of the dome.

199. When a dome is intended to support a heavy lantern, it may require the principal ribs to be stronger than can be obtained out of a piece of timber; but the framing may always be made sufficiently strong by using two ribs, with braces between, and tied together by radial pieces across from rib to rib. A truss of this form is shown by *fig.* 76, which would sustain a very heavy lantern if the curve of equilibrium were to pass in the middle between the ribs, as the dotted line does in the figure. The proper form for the curve will be found by the equations in art. 65, Sect. I.

200. Where a light dome is wanted, without occupying much space, the ribs may be placed so near to each other that the boards may be fixed to them without rafters, or short struts may be put between the ribs, as shown by *fig.* 77.

In a splendid collection of specimens of carpentry, published by M. Krafft, there are methods of finding the position of the principal timbers in domes and roofs shown, which were proposed by M. Stierme, a carpenter of Wirtemburg*. Krafft's work contains no explanation of these methods, and they appear to me to be destitute of any thing like sound principle, particularly as applied to domes, and are only noticed as a caution to the young student.

* Recueil de Charpente, par M. Krafft, deuxième partie, planche 70 et 34.

# SECTION VI.

## OF THE CONSTRUCTION OF PARTITIONS.

201. PARTITIONS, in carpentry, are frames of timber for dividing the internal parts of a house into rooms: they are usually lathed and plastered, and sometimes the spaces between the timbers are filled with brickwork.

In modern carpentry there is no part of a building so much neglected as the partitions. A square of partitioning is of considerable weight, seldom less than half a ton, and often much more; therefore a partition should have an adequate support: instead of which it is often suffered to rest on the floor, which of course settles under a weight it was never intended to bear, and the partition breaks from the ceiling above.

If it be necessary to support a partition by means of the floors or roof, it should rather be strapped to the floor or roof above it, than be suffered to bear upon the floor below; because in that case the cracks along the cornice would be avoided; and in such cases the timbers of the floor or roof must be made stronger. A partition ought, however, to be capable of supporting its own weight; for even when doorways are so placed that a truss cannot be got the whole depth, it is almost always possible to truss over the heads of the doors.

202. Partitions that have a solid bearing throughout their length do not require any braces, indeed they are better without, as it is easy to stiffen them by means of struts between the uprights, and thus the shrinking and cross strains occasioned by braces are avoided. When braces are introduced in a partition, they should be disposed so as to throw the weight upon points that are sufficiently supported below, otherwise they do more harm than good.

But though it be often practicable to give a partition a solid bearing throughout, it is better not to do so, because all walls settle; therefore the partition should always be supported only by the walls it is connected with, so that it may settle with them. If the partition have a solid bearing, and the walls settle, fractures must necessarily take place.

Also, when a partition is supported at one end by the wall of a high part of the building, and by the wall of a lower part at the other end, it will always crack either close by the walls, or diagonally across.

I state here the consequences that may be expected in the usual kinds of foundations; there may be some where the settlement is so small as to produce no sensible effect; but such instances are rarely met with. Much may be done by making the base of a

wall in proportion to the whole weight it is intended to support; but this belongs to another department of the building art.

In a trussed partition the truss should have good supports, either at the ends or other convenient places, and the framing should be designed accordingly; that is, so that the weight may not act on any other points than those originally intended to bear it. The best points of support are the walls to which the plastering of the partition joins.

203. Partitions are made of different thicknesses, according to the extent of bearing: for common purposes, where the bearing does not exceed 20 feet, 4 inches is sufficient; or, generally, the principal timbers may be made

| | | |
|---|---|---|
| 4 inches by | 3 inches for a bearing not exceeding | 20 feet. |
| 5 ........ | $3\frac{1}{2}$ ........................ | 30 |
| 6 ........ | 4 ........................ | 40 |

And partitions should be filled in with as thin stuff as possible, so that it be sufficient to nail the laths to. Two inches is quite a sufficient thickness. When these filling in pieces are in long lengths, that is, when they exceed 3 or 4 feet, they should be stiffened by short struts between them; or, what is much better, to notch a continued rail across the uprights, nailing it to each.

It should be borne in mind, that in all cases useless timber is only an unnecessary load upon the framing, and increases the risk of failure at a considerable expense.

The thicknesses above mentioned apply only to partitions that have no other than their own weight to bear. When a floor is to be supported by a partition, it must be prepared for that purpose. It would, however, be impossible to give any rules for such partitions, as the design must be varied according to circumstances, which differ so materially in almost every case as to render particular rules useless.

204. The pressure in the direction of any of the pieces may be found by applying the principles given in Sect. I.; and the scantlings of the timbers that would be sufficient to sustain such pressures, may be found by the rules for the stiffness of materials in Sect. II. The following data will assist in forming an estimate of the pressure on the framing of partitions:

| | | |
|---|---|---|
| The weight of a square of partitioning may be taken at ................ | from 1480 pounds to | 2000 pounds per square. |
| The weight of a square of single joisted flooring, without counter flooring .. | .... 1260 ........ | 2000 |
| The weight of a square of framed flooring, with counter flooring ..... | .... 2500 ........ | 4000 |

As great nicety is not required in calculating the scantlings, the highest numbers may be taken for long bearings, and the lowest for short ones; as the one gives the weight in large mansions, the other that in ordinary houses.

The shrinkage of timbers, and still more often imperfect joints, cause considerable settlements to take place in partitions, and consequently cracks in the plastering; therefore it is essential that the timber should be well seasoned, and also that the work should be well framed, as a slight degree of settlement in a partition is attended with worse consequences than is produced by a like degree of settlement in any other piece of framing.

205. *Fig.* 78 shows a design for a trussed partition with a doorway in the middle; the tie or sill is intended to pass between the joisting under the flooring boards. The strongest position for the inclined pieces of the truss is shown by the figure, as the truss would have been much weaker with the same quantity of materials if they had been placed in the position shown by the dotted lines. The inclination of the trussing pieces should never greatly differ from an angle of 40 degrees with the horizon. The horizontal pieces, *a a*, are intended to be notched into the uprights, and nailed: in partitions for principal rooms, one on each side might be used.

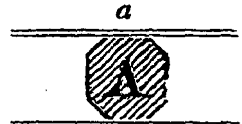
206. When a doorway is near to the side of a room, which is often necessary, in order to render a room either convenient or comfortable, the partition should be trussed over the top of the door, as shown in *fig.* 79. The posts, A, B, should be strapped to the truss, and braces may be put in the lower part of the truss in the common way; but it would be better to halve these braces into the uprights, which would bind the whole together.

In order to save straps, the posts A, B, are often halved into the tie CD; in that case, the tie should be a little deeper; and as the tie may be always made strong enough to admit of halving, perhaps this is the best method.

Partitions should always be put up some time before they are plastered; that the timbers, should they cast, may be put right again. This precaution is not so necessary where timber has been a considerable time cut to the proper scantlings, or well seasoned.

The arrises of all timbers exceeding 3 inches should be taken off, to allow room for a sufficient key for the plaster: that is, if A be the section of a post or brace, to be lathed at *a* and *b*, it must be bevelled so as to reduce the faces at *a* and *b* to less than 3 inches.

*a*




*b*

# SECTION VII.

## OF THE CONSTRUCTION OF CENTRES FOR BRIDGES.

207. A CENTRE is a timber frame, or set of frames, for supporting the arch-stones of a bridge during the construction of the arch.

The qualities of a good centre consist in its being a sufficient support for the weight or pressure of the arch-stones, without any sensible change of form throughout the whole progress of the work, from the springing of the arch to the fixing of the key-stone. It should be capable of being easily and safely removed, and designed so that it may be erected at a comparatively small expense.

In navigable rivers, where a certain space must be left for the passage of vessels, and in deep and rapid rivers, where it is difficult to establish intermediate supports, and where much is to be apprehended from sudden floods, the frames should span the whole width of the archway, or be framed so as to leave a considerable portion of the arch-way unoccupied. In such cases a considerable degree of art is required to make the centre an effectual support for the arch-stones, particularly when the arch is large.

But in narrow rivers, and in those where the above-mentioned inconveniences do not interfere with the work, the framing may be constructed upon horizontal tie beams, supported in several places by piles, or frames fixed in the bed of the river; and the construction is comparatively easy.

In large arches, when the arch-stones are laid to a considerable height, they often force the centre out of form, by causing it to rise at the crown, and it is often necessary to load the centre at the crown to prevent such rising; but this is a very imperfect remedy. Notwithstanding the subject has been considered by several very eminent men, their works are not much calculated to instruct the carpenter how to avoid this difficulty; indeed their object seems to have been exclusively to calculate the strength of a centre already designed, instead of showing the principles on which it ought to be contrived; and even in calculating the strength they are very imperfect guides, because they have not attempted to find what forces would derange a centre, but only the force that might be supported without fracture *.

Mr. Smeaton, in his designs for centres, always contrived his scantling to suit the general scantlings of timber, with the view of saving labour, and of leaving the timber in as useful a state as possible when it was done with †. This practice is a good one,

* See Pitot on Centres, Mem. de l'Acad. 1726; Couplet on ditto, Mem. de l'Acad. 1729; Frezier's Coupé des Pierres, tome iii. p. 408.

† Reports, vol. iii. p. 236.

and ought to be imitated, as a centre or a scaffold is not like a permanent work. Nevertheless, some knowledge of the principle of disposing the parts is necessary, and also of estimating the degree of stiffness that will be actually required in a centre; otherwise more timber may be wasted than if it had been cut to the proper scantling at the first, as all timber that has been used in a centre is more or less injured.

208. Centres are composed of several separate vertical frames or trusses, connected together by horizontal ties, and stiffened by braces. When the frames have to span the whole width of the archway, the offsets of the stonework afford a most substantial abutment for the support of the centre. The frames or trusses of centres are generally placed from 4 to 6 feet apart, according to their strength, and the pressure they have to support. In general, there is one frame under each of the external rings of arch-stones, and the space between is equally divided by the intermediate frames.

A bridge of three arches will require two centres, one of five arches requires three centres, &c.

*Pressure of the Arch-stones upon Centres.*

209. Before proceeding to investigate the disposition and stiffness of centres, the point must be determined at which the arch-stones first begin to press upon the centre; and also the pressure upon it at different periods of the formation of the arch.

It has been found by experiment, that a stone placed upon an inclined plane does not begin to slide till that plane has an inclination of about 30 degrees from the horizontal plane*, and till a stone would slide upon its joint, or bed, it is obvious that it would not press upon the centre. Also, when a hard stone is laid with a bed of mortar it will not slide till the angle becomes from 34 to 36 degrees. A soft stone bedded in mortar will stand when the angle which the joint makes with the horizon is 45 degrees, if it absorb water quickly; because in that case the mortar becomes partially set†. Similar results have been obtained by other experimentalists; therefore we may consider the pressure, in general, to commence at the joint which makes an angle of about 32 degrees with the horizon.

This angle is called the angle of repose, and if we suppose the pressure to be represented by the radius, the tangent of this angle will represent the friction; hence, considering the pressure as unity, the friction will be 0·625. Perronet estimates the friction at 0·8 ‡; but it is erring on the safe side to take the lower result.

210. The next course above the angle of repose will press upon the centre, but only in a small degree; and the pressure will increase with each succeeding course. The

* Rondelet, l'Art de Bâtir, tome iv. p. 273. † Idem.

‡ Memoir sur le Cintrement et le Decintrement des Ponts, in the Memoirs of the Academy of Sciences at Paris for 1773.

relation between the weight of an arch-stone, and its pressure upon the centre, in a direction perpendicular to the curve of the centre, may be determined from the following equation: $W(\sin. a - f \cos. a) = P$.

Where W is the weight of the arch-stone, P=the pressure upon the centre, $f$=the friction, and $a$=the angle which the plane of the lower joint of the arch-stone makes with the horizon.

| | | |
|---|---|---|
| 211. When the angle which the joint makes with the horizon is ........................ | 34 degrees | P=·04 W. |
| ........................................ | 36 ...... | P=·08 W. |
| ........................................ | 38 ...... | P=·12 W. |
| ........................................ | 40 ...... | P=·17 W. |
| ........................................ | 42 ...... | P=·21 W. |
| ........................................ | 44 ...... | P=·25 W. |
| ........................................ | 46 ...... | P=·29 W. |
| ........................................ | 48 ...... | P=·33 W. |
| ........................................ | 50 ...... | P=·37 W. |
| ........................................ | 52 ...... | P=·4 W. |
| ........................................ | 54 ...... | P=·44 W. |
| ........................................ | 56 ...... | P=·48 W. |
| ........................................ | 58 ...... | P=·52 W. |
| ........................................ | 60 ...... | P=·54 W. |

But when the plane of the joint becomes so much inclined that a vertical line passing through the centre of gravity of the arch-stone does not fall within the lower bed of the stone, the whole weight of the arch-stone may be considered as resting upon the centre, without material error. We have thus an easy method of estimating the weight upon a centre, at any period of the construction, or when any portion of the arch-stones is laid, as well as when the whole weight it has to sustain is upon it.

212. As an example, let it be required to determine the pressure of the arch-stones upon 20 degrees of the centre, counting from the joint which makes an angle of 32 degrees with the horizon.

RULE. Take out of the table above the decimals opposite every second degree for the first 20 degrees, that is, from 32 to 52 degrees, and add them together. Multiply the sum thus found by the weight of a portion of the arch-stones comprehended between 2 degrees; the product will be equal to the pressure of 20 degrees of the arch upon the centre.

Suppose the frames of the centre to be 5 feet from middle to middle, and the depth of the arch-stones to be 4 feet; also, that the space comprehended between 2 degrees of the arch measured at the middle of the depth of the stone is 1·5 feet. The solid

content will be found to be 30 cubic feet; and, if the weight of a cubic foot of the stone be 150 pounds, the weight of 2 degrees will be $30 \times 150 = 4500$ pounds.

Then adding together the decimals for 20 degrees, that is, from 32 degrees to 52, the sum is 2·26. This sum multiplied by the weight of 2 degrees, or 4500 pounds, gives 10,170 pounds for the pressure of 20 degrees upon one frame of the centre.

213. It is evident from the table, that the pressure increases very slowly till the joint begins to make a considerable angle with the horizon; and it is of importance to bear this in mind in designing centres, because the strength should be directed to the parts where the strain is greatest. For instance, at the point where the joint makes an angle of 44 degrees with the horizon, the arch-stone only exerts a pressure of one-fourth of its weight upon the centre; where the angle of the joint is 58 degrees, the pressure exceeds half the weight; but near to the crown the stones rest wholly upon the centre. Now it would be absurd to make the centre equally strong at each of these points; besides, by such a method there would not be the means of applying the strength where it is really required, without interfering with ties and braces, that are only an incumbrance to the framing.

When the depth of the arch-stone is nearly double its thickness, the whole of its weight may be considered to rest upon the centre when the joint makes an angle of about 60 degrees with the horizon. If the length be less than twice the thickness, it may be considered to rest wholly upon the centre when the angle is below 60 degrees; and if the length exceed twice the thickness, the angle will be considerably above 60 degrees before the whole weight will press upon the centre.

214. But though the error introduced, by considering all the arch-stones above the joint that makes an angle of 60 degrees with the horizon as pressing wholly on the centre, is not a very considerable one, it may be desirable to use a method that approaches nearer to the truth when the arch is circular. However inclined a joint may be, a certain portion of the force of the arch-stone will be lost in friction, without the joint becomes sensibly vertical. And in any case the pressure perpendicular to the curve of the centre will be expressed by the equation $W(\sin. a - f \cos. a) =$ perpen. pressure $= P$. But it will be more convenient to measure the angle $a$ from the vertical line passing through the crown; then $W(\cos. a - f \sin. a) = P$.

If the angle included between the joints of one arch-stone be denoted by $a$, and the stones be alike in weight, and in the portion of the arch they occupy; then the pressure of any number $n$ of arch-stones upon the centre will be expressed by the equation

$$W\left(\frac{\cos. \frac{n}{2}a \times \sin. \frac{n+1}{2}a - f \sin. \frac{n}{2}a \times \sin. \frac{n+1}{2}a}{\sin. \frac{1}{2}a}\right)^{*} = \text{pressure} = P,$$

* This expression is equal to W (sum of cosines of $na - f \times$ sum of sines of $na$), and the sum of the sines and cosines are found by equations 27 and 29, p. 69, of Dr. Hutton's Course of Mathematics, vol. iii.

The magnitude of the arc $a$ being ascertained, the sines and cosines to a radius of unity may be taken from a table of natural sines. But the calculation will be more simple under the following form: $\dfrac{\mathrm{W}\times\sin.\frac{n+1}{2}a}{\sin.\frac{1}{2}a}\times(\cos.\tfrac{1}{2}na - f\sin.\tfrac{1}{2}na.)$ (A.)

The computation becomes easier by using a table of logarithms.

When the arch-stones are small, the pressure upon the centre is greater than when they are large; and as an arch-stone will seldom be smaller than would extend one degree of the arch, the pressure in that case may be assumed as sufficiently accurate; the error being always in excess till the arch-stones extend less than one degree each. Now the number of degrees between the middle or crown and the angle of repose is 58; therefore, by equation (A) the whole pressure upon the semi-centre may be determined. The calculation by logarithms may be done as follows. The equation is more convenient for logarithms arranged thus: $\mathrm{W}\times\left(\dfrac{\cos.\frac{n}{2}a\times\sin.\frac{n+1}{2}a}{\sin.\frac{1}{2}a}-\dfrac{f\times\sin.\frac{n}{2}a\times\sin.\frac{n+1}{2}a}{\sin.\frac{1}{2}a}\right)$ (B.)

*Example.* We have $a=1$ degree, $n=58$, and (by art. 209) $f=0{\cdot}625$. Therefore,

$$\text{Log. cos. }\frac{n}{2}a=\text{log. cos. }29^\circ = -1{\cdot}941819$$
$$\text{Log. sin. }\frac{n+1}{2}a=\text{log. sin. }29^\circ\,30' = -1{\cdot}692339$$
$$\overline{\quad -1{\cdot}634158 \quad}$$
$$\text{Log. sin. }\tfrac{1}{2}a=\text{log. sin. }0^\circ\,30' \ldots = -3{\cdot}940842$$
$$\text{Log. }49{\cdot}36 \ldots\ldots = 1{\cdot}693316$$

$$\text{Log. }f=\text{log. }0{\cdot}625 \ldots\ldots = -1{\cdot}795880$$
$$\text{Log. sin. }\frac{n}{2}a=\text{log. sin. }29^\circ = -1{\cdot}685571$$
$$\text{Log. sin. }\frac{n+1}{2}a \ldots\ldots = -1{\cdot}692339$$
$$\overline{\quad -1{\cdot}173790 \quad}$$
$$\text{Log. sin. }\tfrac{1}{2}a \ldots\ldots = -3{\cdot}940842$$
$$\text{Log. }17{\cdot}1 \ldots\ldots = -1{\cdot}232948$$

And $49{\cdot}36-17{\cdot}1=32{\cdot}26$; consequently, $32{\cdot}26\,\mathrm{W}$ is equal to the pressure of the semi-arch upon the centre, where W is the weight of a part of the ring of arch-stones that extends one degree.

## *On Designing Centres.*

215. In designing frames for centres there are two things which require particular attention. The centre should be sufficiently strong to support any part, or the whole of the pressure; and it should be capable of supporting any part without a sensible change of form. To accomplish the first object, the strains must not act very obliquely upon the supporting pieces; and the magnitude of the parts must be proportioned to the

strain upon them. The second object will be obtained by disposing the parts so that the stress may prevent any part rising, instead of causing it to rise, as is too common in centres.

216. Centring for arches, of small span, is easily managed, and when it is possible to obtain intermediate supports at a comparatively small expense, even large centres are not difficult. The centring of Conon Bridge, of which the span is 65 feet, and rise 21·8 feet, is a good example of this kind of construction; it was designed by Mr. Telford*. See *fig.* 81.

The justly celebrated Smeaton designed the centre, *fig.* 80, for Coldstream Bridge; and as a description I cannot offer the reader any thing to illustrate it better than his own directions that accompanied the design. He says, "What I had therefore in view was to distribute the supporters equally under the burden, preserving at the same time such a geometrical connection throughout the whole, that if any one pile, or row of piles, should settle, the incumbent weight would be supported by the rest."

"With respect to the scantlings," he adds, "I did not so much contrive how to do with the least quantity of timber, as how to cut it with the least waste; for, as I took it for granted the centre would be constructed of East Country fir, I have set down the scantlings, such as they usually are, in whole balks, or cut in two lengthways †." The bridge was of stone; 25 feet wide, from outside to outside; the centring consisted of 5 frames, or ribs, framed in the manner represented in *fig.* 80. The span of the centre arch was 60 feet 8 inches, and the dimensions of the principal timbers are figured upon the design.

217. But where intermediate supports cannot be obtained, centres require to be constructed with more care, as well as more attention in forming the design. It is obvious that laying a load upon the haunches must have a tendency to raise the centre at the crown, unless the frame be so contrived that it cannot rise there under the effect of any force that it may have to sustain at the haunches. This principle the French engineers did not understand, and consequently some of their centres underwent a change of form with every course of stones that was laid upon them. I cannot perhaps show better the importance of the principle of preventing any change of form by the disposition of the framing, than by pointing out the defects of the centre designed by Perronet for the Bridge of Neuilly, and comparing it with some that have been employed in Britain. *Fig.* 82, *Plate* XIV. represents the centre of the Bridge at Neuilly. It is obvious that such a centre loaded at A and B, must rise at C; and the timbers being nearly parallel, the strains produced by a weight resting on any point must have been prodigious; consequently, the yielding at the joints was very considerable. It is a kind of framing well enough adapted to support an equilibrated load, distributed over

* Edinburgh Encyclopædia, art. Bridge.

† Smeaton's Reports, vol. iii. p. 236, plate 10,

its whole length; but is one of the worst that can be adopted for a centre, or for supporting any variable load. It must have consumed an immense quantity of timber, and yet without the advantage of connection. The quantity is crowded into so small a space that it has a light appearance, and consequently has obtained the approbation of those that are incapable of penetrating further than the apparent surface of things they pretend to examine. The centres for the bridges of Nojent, Cravant, St. Maxence, and Nemours, were designed on similar principles, and were found to be equally defective.

218. *Fig.* 83, *Plate* XIV. represents the centre of the Waterloo Bridge*, designed by Mr. Rennie. In this centre, by a better disposition of its timbers, a load at A could not cause the centre to rise at C, without reducing the length of the beam DE, and the one opposite to it. There is an excess of strength in some of its parts, and it is complicated in the extreme; but, on the whole, it is a very judicious combination. The centre of Blackfriars Bridge appears to have been taken as the ground-work; and there are some improvements, both in form and construction, that do much credit to the able engineer who has made them.

219. Let the line ACA′, *fig.* 84, *Plate* XV. represent the curve of an arch; and let us suppose the arch-stones to begin to press upon the centre at B, B′, where the joints make an angle of 32 degrees with the horizontal plane; and that the laying of the arch-stones proceeds alike on each side. Now if two trussed frames, EDH, E′D′H, abut against each other at C, the point C cannot rise in a sensible degree from the pressures at D, D′, and much additional security may be obtained by adding the piece FF′, with the pieces FI, F′I′.

The framing of this centre commences on each side nearly at the point where the arch-stones first begin to press on the centre, the curved rib must be strong enough to bear the parts between BD, and DC, but the bearings may be shortened by making the abutting blocks at D, D′ longer. The beams EC, E′C, will act as ties till the arch-stones are laid beyond the points D, D′; they will then begin to act as struts, and will continue to act as struts after that, till the whole be laid.

This disposition cannot be employed where the span is large, because it then requires very long pieces of timber; and the points of support for the curved rib become too far apart to be supported by timbers of the usual dimensions.

220. Let the built beams, EF, FF′, and F′E′, *fig.* 85, *Plate* XV. be each trussed, and abut against each other at F and F′; then it is obvious, that when the loads press equally at D, D′, they will have no tendency to raise the beam FF′ in the middle, unless it be not sufficiently strong to resist the pressure in the direction of its length; and, as it is easy to give it any degree of strength that may be required, a centre of this form

* From the Supplement to the Encyclopædia Britannica, art. Bridge, plate xliv.

may, with a little variation in the trusses, be applied with advantage to any span which will admit of a stone bridge. When timber is not to be had of sufficient length, the beams EF, FF′, and F′E′, may be built in the manner directed for building beams. See Sect. IX.

The examples and remarks already given will give the reader a clear notion of the kind of arrangement which is proper for a centre; it would be an easy matter to multiply examples, but having said enough to show the nature of the principle, I must leave him to design for himself, and proceed to make some remarks on the construction.

### *On the Construction of Centres.*

221. The principal beams of a centre should always abut end to end when it is possible. It is a very good method, where timbers meet at an angle, to let them abut into a socket of cast iron, as has been done in the centre of Waterloo Bridge. See *fig.* 83, *Plate* XIV. The timbers should intersect one another as little as possible, as every joining causes some degree of settlement, and halving the timbers together always destroys nearly half their strength. The pieces which tend towards the centre, and which perform a similar office to the king post of a roof, should be notched upon the framing; and they should be in pairs, that is, one on each side of the frame, and well bolted together. Some of the braces may also be applied in the same manner with much advantage. The braces marked *aa*, in *fig.* 85, are supposed to be done in this way.

Ties should be continued across the frames in different parts, particularly at any point where many timbers meet; and diagonal braces across the frames are also necessary, to secure them from lateral motion.

A sound and firm centre is a most desirable thing in the construction of an arch, as the motion of a weak one destroys the cohesion of the cementing materials. Sometimes centres have completely failed. In erecting a large arch over the river Derwent, on the line of the Glossop and Sheffield road, as they were proceeding to lay the key-stone, the centre gave way, and fell with a tremendous crash into the river. Several lives were lost *.

### *On Removing Centres.*

222. The frames of a centre are placed upon double wedges, or sometimes on blocks with wedge-formed steps cut in them; and when the centre is to be eased, the wedges,

* Morning Chronicle of August 27, 1819.

or wedge-formed pieces, are driven back so far as to suffer the centre to descend regularly. This operation should be very leisurely performed; in order that the arch, in taking its proper bearing, may not acquire any sensible degree of velocity; as it would be a dangerous experiment to let it settle too rapidly.

In small centres the wedges are driven back with mauls, men being stationed at each pair of wedges for that purpose. But in larger works a beam is mounted, as a battering ram, to drive the wedge-formed blocks back. Before driving back the wedges it is a good precaution to mark them, so that it is easy to ascertain when they are regularly driven.

It is a great advantage in striking centres to be able to suffer them to rest at any part of the operation; and in this, as well as in some other respects, the methods of lowering and easing centres practised in Britain, are infinitely superior to those adopted by the French engineers. The French method consists in destroying, by little and little, the ends of the principal supports; a work of difficulty as well as of danger, and which cannot be done with so much regularity as with wedges.

The centres of Blackfriars Bridge, and the Waterloo Bridge, were placed upon blocks, with wedge-formed steps cut in them; as is shown in *fig.* 83, *Plate* XIV. Another method consists in forming the steps on beams that reach across the whole width of the bridge, passing between the feet of the trussed frames, and the posts that support them. In *fig.* 84, *Plate* XV. the centres are supposed to be done in this manner. The frames being thus placed upon continued wedges, the centre may be struck without it being necessary to have workmen beneath; consequently it is less dangerous, and can be done with a less number of men. In consequence of nine men having been killed in removing the centre of a military work, Mr. Richard Williams proposed a similar method to the above, which was used at Chatham, in 1807, with success*.

*On computing the Strength of Centres.*

223. It fortunately happens that simple designs are best calculated for centres; for it would be very difficult to form any thing like an accurate estimate of the strength of a complicated one. I will here show some approximate methods of fixing upon the proper scantlings for the timbers for the designs I have given; and add to one of them some examples, in numbers, which will serve to illustrate the subject.

In the centre, *fig.* 84, *Plate* XV. the stress may be considered, in as far as it tends to strain the frame EDH; also the stress upon the pieces EH, H′E′, when the whole load is upon them; and, lastly, the strain upon the posts GK, G′K′.

* Transactions of the Society of Arts, vol. xxxiii. p. 128.

First, Let the pressure of the arch-stones between B and C be calculated, if the arch be circular, by art. 214; and if it be elliptical, by art. 211. Consider half this weight as collected at D, and acting in the direction DF, which will be sufficiently accurate for our present purpose. Then, by attending to the rules in art. 14 and 17, Sect. I. the strains in the directions of each of the beams composing the frame EDH will be found; and the dimensions of the pieces that would resist them are to be determined by the rules for the stiffness of beams in Sect. II. or by the rule at the end of this article.

Secondly, Compute the pressure of the arch between D and C, and consider it as acting at C in a vertical direction; then the strain on the beams EH, H'E', will be found by the rules above referred to.

Lastly, Let the whole pressure of the arch-stones between B and C, together with half the weight of the centre itself, be considered as acting at the point E in a vertical direction, and find the dimensions of the supports KG, K'G', that would resist this pressure.

But in these calculations it must be observed, that if the length of any of the pieces in feet be not greater than 1·25 times the breadth, or least dimension in inches, it will cripple at the joint rather than bend. Thus, if a piece be 8 inches in breadth, then its length must be $1 \cdot 25 \times 8$, or 10 feet; otherwise it will sink at the joint rather than bend.

Therefore, when the length between the points where it is braced is less than in this proportion, instead of finding the scantlings by the rules for the stiffness of beams, they must be determined by the following rule.

Rule. The pressure upon the beam in pounds divided by 1000 gives the area of the piece in inches, or that of the least abutting joint, if that joint should not be equal to the section of the piece.

As all long pieces in a centre may be rendered secure against bending by cross braces, or radial pieces notched on and bolted to them, this rule may almost always be applied for centres, instead of the rules in Sect. II.

224. In the centre, *fig.* 85, the beams EF, FF', and F'E', constitute the chief support; the arch is an ellipse, and consequently a considerable part of it will bear almost wholly upon the centre. But from what has been shown respecting the pressure of the arch-stones, it will appear that if we take the whole weight of the ring between D and C, and consider it to act in the direction HF at the joining F, it will be the greatest strain that can possibly occur at that point from the weight of the arch-stones. Produce the line HF to $f$, and make $hf$ to represent the pressure, draw $he$ parallel to the beam EF. Then, as $hf$ represents the pressure of the arch between D and C, $he$ will be the pressure in the direction of the beam FE; and $ef$, the pressure in the direction of the beam FF': and these beams must be of such scantlings as would sustain these pressures.

Let the weight of the arch from H to H' be estimated, and if two-thirds of this weight be considered to act at C in a vertical direction, it will be the greatest load that is likely

to be laid at that point, and the dimensions for the parts of the truss FCF′ must be found so as to sustain that pressure.

The frame, EDF, may be calculated to resist half the pressure of the arch-stones between B and H; that pressure being found by art. 211.

The whole weight of the arch-stones from D to C, together with the weight of the centre itself, may be considered as acting in a vertical direction at E, and the supports at GE should be sufficient to sustain the action of this pressure.

To determine the scantlings of the ribs that support the weight between H and C, or D and H, &c. calculate the weight of that part of the arch which rests upon it, and consider it as a weight uniformly diffused over the length. The proper scantling will then be found by the rule in art. 98. These bearings may be much shortened by lengthening the blocks against which the inclined beams of the truss abut.

## *Examples.*

225. *Example* 1. To determine the principal scantlings for a centre for a stone arch 50 feet span to the design *fig.* 84. A cubic foot of the stone weighing 130 pounds, and the depth of the arch-stones 3 feet; the frames 5 feet from middle to middle.

The arch is described with a radius of 26 feet; consequently, 27·5 feet is the radius of an arc passing through the middle of the depth of the arch-stones; and to find the length of this arch for one degree, multiply the length of the arch for a radius of unity, which is ·01745329, by 27·5 feet. This is most easily done by logarithms.

$$\begin{array}{lr} \text{The logarithm of } \cdot01745329 \text{ is} & -2\cdot241877 \\ \text{Log. of} \ldots\ldots\ldots 27\cdot5 \ldots\ldots = & \underline{1\cdot439333} \\ \text{Log. of} \ldots\ldots\ldots \cdot48 \;\ldots\ldots = & -\underline{\underline{1\cdot681210}} \end{array}$$

And $5 \times 3 \times \cdot48 = 7\cdot2$ feet, the solid content of one degree of the ring of arch-stones. But, by art. 214, $W \times 32\cdot26 = 7\cdot2 \times 32\cdot26 \times 130$ pounds$=30{,}195$ pounds, for the pressure of that part of the ring between B and C. Then suppose this pressure to act in the direction DF, and in order to render the operation more simple, call it 31,000 pounds. Draw *df*, in No. 2, *Plate* XV. parallel to DF; set off *df* equal 31 parts, by any convenient scale; and draw *e b* parallel to the beam EH; also draw *de* and *dh* parallel to the principal rafters of the frame EDC. Now when *dh* is measured by the same scale as *df*, it will measure 70 parts; and as both the rafters make the same angle with straining force, the strain on each will be 70,000 pounds. Let the abutting joint be equal to the section of the rafter, then $\frac{70000}{1000}=70$ inches, for the area of the section of each rafter, or nearly $8\frac{1}{4}$ inches square. The strain in the direction of the length of the tie beam EH need not be calculated, because when it is sufficiently strong to resist

the other strains to which it is exposed, its strength to resist tension will always be above what is necessary.

Our next operation is to calculate the weight or pressure of the arch-stones between B and C. This may be done by common arithmetic, according to the method pointed out in art. 214, to show the superiority of the logarithmic process. The weight of one degree of the ring is the same as before, that is, $W=7\cdot2\times130=936$ pounds, and the space between B and C is 32 degrees; therefore $n=32$. Hence $\cos.\frac{1}{2}na-f\sin.\frac{1}{2}na=$ $\cos.16^{\circ}-f\sin.16=\cdot96126-\cdot27564\times\cdot625=\cdot788985$. And $\dfrac{W\sin.\frac{n+1}{2}a}{\sin.\frac{1}{2}a}\times\cdot788985=$ $\dfrac{936\times\cdot284}{\cdot00873}\times\cdot788985=24022$ pounds, the pressure of the part BC upon the centre*.

By drawing lines parallel to the directions of the straining force and the beams, we find the pressure in the direction of the beam EH to be nearly 23,000 pounds; therefore, $\dfrac{23000}{1000}=23$ inches, the area of the section of the beam: but it must be made a little larger than this, in order to have abutments for the other parts of the truss.

To find the dimensions of the supports required at KG, I have given an approximate rule in art. 223, calculating according to it.

| | |
|---|---|
| The pressure on the centre has been found to be | 31,000 pounds. |
| The weight of half the centre may be stated at | 5,000 |
| Therefore the vertical pressure at K will be ... | 36,000 |

This force would produce a pressure of nearly 41,000 pounds in the direction KG; hence $\dfrac{41000}{1000}=41$ inches, the area of the support required at K.

*Example* 2. To find the strain upon the principal supports of the centre, in *fig.* 85, *Plate* XV.; the depth of the arch-stones being 5 feet, the frames 5 feet from middle to middle, and the stone 130 pounds per cubic foot. The pressure of the arch-stones upon the centre, estimated by the methods detailed in art. 212, will be about 130,000 pounds; and measuring the proportions of the forces by the diagram, No. 3, *Plate* XV. the pressure in the direction of the beam FF′ will be 220,000 pounds, and the pressure in the direction FE will be 230,000 pounds; consequently, the area of the horizontal beam should be 220 inches, and may consist of two beams 10 inches by 11 inches. The area of the inclined beam, EF, should be 230 inches, and may consist of two beams, 11 inches by $10\frac{1}{2}$ inches each.

* The operations of multiplication and division are not given at length, because it would have extended the volume considerably, without conveying any more useful information, to have done so in each example.

# SECTION VIII.

## OF WOODEN BRIDGES.

226. THE oldest wooden bridge that we have any account of is the Bridge of Sublicius, which existed at Rome in the reign of Ancus Martius, about 500 years before the Christian era. It owes its celebrity to the combat of Horatius Cocles, a renowned Roman knight, who saved the city by a noble defence of this bridge; which, it is said, was put together without iron or nails.

227. The next in point of antiquity was that erected by Julius Cæsar, for the passage of his army across the Rhine. It is described at some length in his Commentaries; and Alberti, Palladio, Scamozzi, and others, have attempted, from the description, to restore the design; but their representations differ considerably. Cæsar's army passed over this bridge ten days after they began to carry the timber to erect it.

228. The bridge built by Trajan over the Danube appears also to have been of timber, except the piers, which were of stone; at least so it is represented in basso-relievo upon Trajan's Column. The roadway of this bridge appears to have been supported by three concentric curved ribs of timber, connected by radial pieces; and is certainly a good specimen of the art of building timber bridges at that early period. Trajan's Bridge consisted of twenty or twenty-two stone piers, with wooden arches; each arch above 100 feet span*.

229. In the middle ages, when bridges began to be established on the passages over the principal rivers, they were almost always constructed with piers, at from 15 to 20 feet apart, consisting of one or more rows of piles. These piers were generally defended by a kind of jetty to break the ice, which also protected the piers from the shock of bodies borne down by the current; nevertheless, in process of time, and from the frequent repairs that were necessary to protect the piers, the water-way generally became almost wholly blocked up; and, consequently, the bridge soon became incapable of sustaining the pressure of water which accumulated in high floods.

The whole of the construction of these bridges was of that kind, where abundance of material is made to supply the skill of the artist; yet there are cases where a similar, but lighter kind of wooden bridge, may be employed with much advantage; that is, in places not subject to floods, or for raising a road across a valley; and, generally, for any situation where the piers can be kept light.

230. A bridge that was built by Palladio over the Brenta, near Bassano, is a good

* Gibbon's Rome, vol. vii. p. 126, note, 8vo. edit.

example of this kind of bridge. (See *Plate* XVI. *fig.* 88.) Also, the Bridge of St. Clair, on the Rhone, built by Morand*. In the latter bridge the piers were not constructed in the usual manner, but shorter piles were driven, and cut off a little below low-water mark. On the heads of these piles horizontal pieces were placed, so as to receive the posts to sustain the beams of the roadway to which these horizontal pieces were secured with straps. As that part of the pier which is alternately wet and dry is subject to very rapid decay, this method renders it easy to repair it without disturbing the lower piles.

231. Palladio, in his Treatise on Architecture, has given several designs for bridges, which display a considerable degree of knowledge of the subject; indeed, many of the designs of the present time are merely improvements of the principles exhibited in his valuable work. Palladio appears to have been the first among the moderns who attempted a species of construction that would render numerous piers unnecessary, and so as to avoid exposing any part of the timber work to the shock of bodies carried down by the current. The bridge he erected over the torrent of Cismone, near Bassano, was of this kind, and the span 108 feet. (See *Plate* XVI. *fig.* 86.)

Among the designs for wooden bridges given by Palladio, the most remarkable is that exhibited by *fig.* 87; as it appears to have been the first idea of constructing a system of what may be termed framed *voussoirs;* similar to the arch-stones of a stone bridge; a principle that has since been adopted with much success both in timber and in iron bridges.

232. Of the modern methods of construction, the best appears to be that of forming curved ribs for the support of the roadway; and this principle seems to have been first applied to bridges by Mr. Price, in his Treatise on Carpentry. Mr. Price's method may be stated as follows: He proposes the curved rib to rise about one-sixth of the opening, and to divide it into a convenient number of equal parts, according to the span, or to suit the lengths of the timber. For a bridge of 36 feet span, he proposes to make the ribs of pieces of oak in 5 lengths, and 3 inches in thickness; each rib to consist of two thicknesses, one 12 inches deep, and the other 9 inches deep; the joints crossed, and the thicknesses keyed together with wooden keys. Two of these ribs with joists framed between, he says, will be sufficient to support the roadway†.

Since the publication of Price's work, this method of construction has been brought to considerable perfection in Germany, and other places on the continent, and in America. The following particulars respecting some of the most celebrated wooden bridges cannot fail of being interesting to the reader.

233. The famous wooden arch of 250 feet span, across Portsmouth River, in North America, is put together with wooden keys similar to those proposed by Mr. Price; indeed it is precisely his method of construction applied to a larger span, excepting a

* Gauthey, tome ii. p. 52.

† British Carpenter, p. 26, edit. 1765.

little difference in the form of the keys. The arch was built by Mr. Bludget, and is described by Colonel Sir Howard Douglass, Bart. in his work on Military Bridges, who brought from America an accurate drawing of this ingenious structure.

"The arch is composed of three concentric arcs, ABC, DEF, GHI (*fig.* 89, *Plate* XVI.) of which that in the centre, DEF, and the corresponding arches on the other two sets, support the floor of the bridge. The circular beams, ABC, DEF, GHI, are connected with each other by pieces of hard wood, *a c*, *a c*, and a wedge *b* (*fig.* 90) at the parts 1, 2, 3, 4, &c. (*fig.* 89) where corresponding mortises are prepared. The wedge secures these triple tenons in their mortises, and connects the centre beam, AB, *fig.* 90 (DEF, *fig.* 89) with the other two beams, by the dovetail tenons at the extremities of the keys *ac*, *ac*." "Each circular beam, or arc, ABC, *fig.* 89, is composed of pieces of timber about 12 or 15 feet long, fastened together by dovetail keys and wedges. The joining, D, of every two beams, A, B, *fig.* 91, is in the centre of the opposite beam, C, (breaking joint, as it is termed.) Mortises wider on the outside than on the inside, are cut in the half-beams or pieces, A, B, C, *fig.* 91, so that when they are laid together, the mortises form a double dovetail cell, *fig.* 92, admitting of two pieces of hard wood, *c*, *c*, which are fastened in by the wedge *d**."

Colonel Douglass observes, that "the arch is extremely flexible," and very justly remarks, that diagonal braces would be an improvement. Also, if the three ribs had been placed close above one another, and firmly connected together, the bridge would have been much stronger to resist any unequal load; as then they would have formed a solid beam equal in depth to the sum of their depths. But it would have been still better to have made the same quantity of timber into two ribs with cross ties, and diagonal braces between them. The manner of connecting the parts by means of dovetail keys is not a good one, as the timber must be much weakened by mortises so large as they require, and a very slight degree of shrinkage renders them useless. (See Sect. IX. art. 307.) And it is still more objectionable as applied to the radial pieces, 1, 2, 3, 4, &c. *fig.* 89. These pieces would be much better notched on in pairs, and bolted through.

### *Schaffhausen Bridge.*

234. In Switzerland several excellent wooden bridges have been erected, one of the most celebrated was that at Schaffhausen, constructed in 1757, by John Ulrich Grubenmann, a village carpenter of Tuffen, in the canton of Appenzel, but certainly one of no ordinary capacity. It was composed of two arches, the one 172 feet, the other 193 feet span, supported by abutments at the ends, and by a stone pier in the middle, which

* Essay on the Principles and Construction of Military Bridges, p. 195—197.

remained when the stone bridge was swept away, in 1754. In this bridge the oak beams which rested upon the masonry of the abutments and pier not having been sufficiently seasoned, nor raised from the stone-work so as to admit of a circulation of air round them, they rotted; and the frames began to settle. Grubenmann being dead, a carpenter of Schaffhausen, named Georges Spengler, undertook to remedy that accident, in 1783. He raised the whole bridge, by means of screw-jacks upon scaffolding, supported by piles; and replaced the decayed timbers by others of a better quality. This was the only repair that was done to it during the 42 years it existed; it was burnt by the French army in 1799.

The construction is ingenious, and the principle is shown in *fig.* 103, *Plate* XVIII. (See art. 260.) It has been remarked as the most essential defect, that all the principal supports are so dependent upon one another, that a single part cannot be removed without first supporting the whole bridge. I shall refer the reader for further particulars to the plate and description published by Mr. Taylor, of Holborn; but it is necessary to state, that this bridge, in common with others constructed on the same principle, bent considerably sideways.

Schaffhausen Bridge was finished in less than three years: and Mr. Cox says, that "a man of the slightest weight felt it almost tremble under him; yet waggons heavily laden passed over it without danger." It is often stated that the middle pier was not necessary as a support to it; this however is a mistake, as it certainly would not have borne its own weight without the assistance of the middle pier *.

## *Freysingen Bridge.*

235. The construction of bridges with curved ribs has been much improved by Mr. Wiebeking. Instead of forming the ribs of short lengths, he employs pieces of considerable length, and bends them to the form of the curve. This method has many advantages over that in which short pieces are used; it lessens the number of joints, consequently the ribs are more firm, and less liable to decay. The Bridge of Freysingen, on the Isar, in Bavaria, is one that was constructed according to Mr. Wiebeking's method, in the years 1807 and 1808. It consisted of two arches of 153 feet span, with a rise of 11·6 feet; and the width of the roadway was 25 feet. See *Plate* XVII. *fig.* 94 and 95.

The ribs which supported the roadway consisted of two parts, the one more curved than the other; that which was most curved was built with three courses of beams, of

* Cox's Travels in Switzerland, vol. i. p. 9, 10; Rondelet's l'Art de Bâtir, tome iv. p. 318; Gauthey's Construction des Ponts, tome ii. p. 57.

from 12·6 to 14·5 inches in thickness, and about 46 feet in length. Each beam having been bent to the proper curve by screws or levers, and scarfed and bolted to the rest. The upper part of the rib consisted of only two courses of beams of 15·5 inches each.

Each of the abutments were 21·25 feet in thickness, and rested upon 68 piles. The piles were from 30 to 38 feet long, and 15·5 inches square; and they were driven from 17·4 to 19·4 feet into the ground, with a ram of 1486 pounds weight. The straighter parts of the curved ribs abutted against 5 piles that were driven within about 3 feet of the back of the abutment; these piles were 12·6 inches square, and had 20 feet hold of the ground, and were also further strengthened by building the abutment round them. In the elevation of the bridge, *fig.* 94, the abutment to the left of the figure is supposed to be cut through, to show how the two parts of the rib abut into it.

Each arch consisted of three curved ribs, which were bonded together at seven places, by cross ties, each consisting of several pieces of timber laid one upon another; and these ties supported seven ranges of beams, laid in the direction of the length of the bridge, with diagonal braces between them, and the joisting for the roadway laid across them.

In the spaces, between the springing of the arches and the first cross tie, inclined braces were fixed crossing one another, and similar braces were fixed between the cross ties on each side of the crown of the arch, serving to strengthen the bridge against any lateral strain. The upper part of the ribs were continued into the abutments for the same purpose.

The pier, which sustained the arches in the middle, consisted of 9 vertical piles, of 17·5 inches diameter, driven about 17·5 feet into the bed of the river; and two inclined piles about 46 feet long. The base of the pier was surrounded by a bed of large gravel stones, with the joints filled with water cement. The ends of the ribs abutted into vertical posts, which rested upon horizontal sills, that were secured to the piles by bolts and straps. A lining of strong oak planking was placed between the vertical posts and the piles, and the spaces formed between the planking and the piles were filled with beton. *Fig.* 95 is a section across the bridge close to the pier.

In order to preserve the timbers, the mortises and tenons of the vertical posts were soaked in hot oil; and small gutters were made near the lower ends of the curved ribs and braces to cause the water to run off, instead of settling into the joints. To all the principal timbers two coats of pitch and tar were applied.

The exterior of the bridge was covered with boarding, painted, and dark lines drawn for the joints, so as to imitate a stone bridge. (See the part of the elevation to the right, in *fig.* 94.) The simple inspection of the figure must convince any one that a stone bridge could not be executed with so slight a pier; consequently the bridge must have always appeared what it really was. An attempt at deception ill managed is always regarded with contempt; and it is much to be regretted, that some of the finest specimens of this artist's skill are hid beneath a clumsy imitation of stone-work;

whereas, had they appeared without this disguise, they would have drawn forth the praises of every one. It may be stated in favour of covering wooden bridges with boarding, that it assists in preserving them; but this I am inclined to doubt, as it will retain damp air round the timbers, and cause them to decay perhaps sooner than when exposed to free evaporation.

The arches did not settle regularly in this bridge; the one settled only about 3·4 inches, while the other settled 11·6 inches, and in the manner shown by the dotted line upon the elevation, *fig*. 94. The cause of this irregularity seems to be the want of attention in making the beams regular; consequently, the forces they would exert to regain their original form not being equal, the arch would bulge in the weakest place.

This bridge was entirely destroyed in the campaign of 1809; but the rebuilding, nearly to the same plan, was begun some time ago*.

### *The Bridge of Bamberg.*

236. The Bridge of Bamberg, on the Regnitz, in Germany, is another example of Mr. Wiebeking's methods of construction, and it is the widest span that has been executed according to his principle. It was built in 1809.

It consists of one arch of 208 feet span, with a rise of 16·9 feet, and the width of the roadway is 32 feet. (See *Plate* XVII. *fig*. 96 and 97.) A stone bridge had formerly been erected on the same site, but its heavy piers contracted the water-way so much, that the water, in a flood, accumulated to such a height as to overturn the bridge by its pressure. In consequence of this accident the wooden bridge was made to span the whole width of the river.

In the middle of the width of the bridge, 3 ribs are placed side by side, the middle one being 5 beams in depth at the abutments, but only 3 in depth at the crown; but the ones on each side of it are 3 beams in depth throughout. On each side of the bridge there are two ribs placed side by side, and bolted together; these each consist of 5 beams in depth towards the abutment, and 3 beams in depth at the crown. The depths of the beams are from 13·5 to 15·5 inches. The three compound ribs are united together by cross ties, with diagonal stays or braces between, as in the Freysingen Bridge; also the roadway is constructed in the same manner.

In the elevation, *fig*. 96, the boarding is supposed to be removed from one-half of the bridge, and the abutment cut through, to show the manner of framing the timbers. *Fig*. 97 is a section across the bridge at AA, on the elevation to a larger scale.

The joints of all the parts built into the abutments were well soaked in hot oil, and also covered with sheet lead. The ribs and joists are of fir, the cross ties and plates of oak†.

* Wiebeking's Traité d'une Partie Essentielle de la Science de construire les Ponts, p. 43 to 50.

† Idem, p. 92—95.

237. In a bridge constructed near Ettringen, by Mr. Wiebeking, of which the span was 139 feet, and the rise 8 feet, a different method of strengthening it against lateral motion was adopted. Two ribs were placed parallel to each other at the sides of the bridge, and other two ribs were placed diagonally between them, so as to cross each other in the centre of the bridge*. This method of placing the ribs rendered braces in the flooring unnecessary.

Some very light and elegant wooden bridges have been lately erected by Mr. James Burn, of Haddington; the largest is over the river Don, seven miles from Aberdeen. The span of this bridge is 109 feet 3 inches, the rise 13 feet 4 inches; the radius of curvature 119 feet, and the width of the roadway 18 feet†.

To supply, in some measure, the place of further descriptions of the various kinds of bridges that have been executed, I have, in art. 258 to 265, considered the leading principles of construction; which, with the following tables, will materially assist in informing the reader of what has been done, and consequently enable him to see how far the art is capable of improvement.

238. *A Table of the principal Dimensions of the Bridges constructed by Mr. Wiebeking, with Curved Ribs*‡.

| Name, situation, and date of finishing. | Width of roadway in feet. | Span of the arches in feet. | Rise of the arches in feet. | Radius of curvature in feet. | Span to a rise of unity. | Longest lengths of beams in the ribs in feet. | Depth of beams in the ribs in inches. | The deflexion being 1, the length of the beam was | Distance of cross ties in feet. |
|---|---|---|---|---|---|---|---|---|---|
| Bridge of Bamberg, on the Regnitz, 1809 .. | 32 | 208 | 16·9 | 422 | 12·5 | 53 | 13·5 to 15·5 | 50·8 | 13 |
| Bridge of Shärding, on the Rott, 1809 ..... | 25 | 194 | 18·8 | 258 | 10·26 | 62 | 12·6 to 15·5 | 37·14 | 16 |
| Bridge of Freysingen, on the Isar, 1808 ... | 25 | 153 | 11·6 | 246 | 13·25 | 46 | 12·6 to 14·5 | 32 | 19·3 |
| Bridge of Augsbourg, on the Lech, 1808 .. | 25⅛ | 114 | 10·6 | 158 | 10·72 | 41 | 12·6 to 14·5 | 23·28 | 18·8 |
| Bridge of Ettringen, over the Wertach, 1809 .. | 25 | 139 | 8 | 305 | 17·46 | 46 | 12·6 to 15·5 | 26·2 | 11·6 |
| Diagonal ribs of ditto .. | | 164 | | 355 | | | | | |
| Bridge of Irsingen, over the Wertach, 1808 .. | 25 | 126 | 7 | 285 | 17·91 | 48 | 11·6 to 14·5 | 30 | 15·5 |
| Bridge of Oettingen, over the Inn, 1807 .. | 25 | 103 | 6·8 | 200 | 15·29 | 59 | 13·5 to 15·5 | 24·4 | 17·4 |
| Bridge of Vilshoven, on the Vils, 1809 ...... | 27 | 179 | 11·1 | 378 | 16·09 | 38 | 13·5 to 15·5 | 30 | 11·6 |
| Bridge of Altenmarkt, on the Alz, 1809 ... | 27 | 140 | 12·9 | 203 | 10·96 | 38 | 9·68 | 30 | 7·9 |

* Wiebeking's Traité d'une Partie Essentielle de la Science de construire les Ponts, p. 50—62.

† Edinburgh Encyclopædia, art. Bridge, p. 537.

‡ From Wiebeking's Traité d'une Partie Essentielle de la Science de construire les Ponts, p. 129.

239. *Table of the Spans of some of the most celebrated Wooden Bridges that have been executed in Europe.*

| Name, date, and situation. | Width of roadway. | Span of widest opening. | Rise of widest opening. | Authority. |
|---|---|---|---|---|
| Bridge of Schaffhausen, 1757, by Ulrich Grubenmann, two arches | | 172<br>193 | | Cox's Travels. |
| Bridge of Kandel, in the Canton of Berne, 1764, by Ritter, constructed of fir | 16 | 166 | | Rondelet, l'Art de Bâtir. |
| Bridge of Walton upon the Thames, by Etheridge, about 1758 | | 130 | 27 | Smeaton's Reports, vol. iii. p. 371. |
| Bridge of Zurich | | 125 | | Gauthey. |
| Bridge of Landsberg, over the Lech, 1807, by Wiebeking, of fir | $22\frac{1}{2}$ | 123 | | Wiebeking. |
| Bridge of Sault, on the Rhone, France | | 110·8 | | This bridge failed in a few years. See art. 263, Gauthey. |
| Bridge over the Don, seven miles from Aberdeen, 1803, by James Burn | 18 | $109\frac{1}{2}$ | $13\frac{1}{2}$ | Telford; Edinburgh Encyclopædia. |
| Bridge of Cismone, by Palladio | | 108 | | Rondelet. |
| Bridge of La Cité, on the Seine, Paris, 1802, by Demoutier, of oak | 34 | 104 | | Gauthey. |
| Bridge of Seurre, on the Saone | | 94 | | Gauthey. |
| Bridge of Tournus, on the Saone, 1801, by Gauthey, of oak | $31\frac{1}{2}$ | $89\frac{1}{2}$ | | Gauthey. |
| Bridge of Granholm, four miles from Aberdeen, by James Burn | $10\frac{1}{2}$ | $71\frac{1}{2}$ | $10\frac{1}{2}$ | Telford; Edinburgh Encyclopædia. |
| Bridge of Choisy, on the Seine, 1811 | | 67 | 9 | Gauthey. |
| Bridge of Chazey, on the Ain | 21 | 64 | | Gauthey. |
| Bridge of Brechin, by James Burn | 15 | 58 | 10 | Telford; Edinburgh Encyclopædia. |
| Bridge of Mulatière, Lyons, on the Saone, by Lallié | $31\frac{1}{2}$ | 57 | | Gauthey. |
| Bridge of St. Clair on the Rhone, by Morand, in 1775 | $42\frac{1}{2}$ | 45 | | Gauthey. |
| Bridge of Bassano, over the Brenta, by Palladio | 27 | 36·8 | | Rondelet. |

## *Of the Design of Wooden Bridges.*

240. The principal objects to be attended to in the design of a wooden bridge are, 1st, the choice of a proper situation; 2ndly, the width of the roadway; 3rdly, the

water-way that ought to be left for the river; and, 4thly, the span of the arches. Each of these is chiefly determined by local circumstances.

The principal object in erecting a bridge is to obtain a more easy and ready communication between the opposite banks of a river, a deep ravine, and places of a like nature; and, in general, the situation ought to be that which is most convenient for the use of the public. Sometimes, however, it happens that the most convenient situation is not the best adapted for the erection of a bridge. In this case the advantages and disadvantages of other situations should be carefully considered, and the site determined so that the means of communication may be as direct as possible, and the access to the bridge commodious.

This determination will be much facilitated by making a correct plan of the course of the river, and of the roads that are to be connected with the bridge. This plan should be sufficiently extensive to give a correct idea of the nature of the river, and of the changes its bed may have undergone; and also of the directions of the roads.

The bridge should always, if possible, cross the stream at right angles; and it is an advantage, when the course of the river is nearly straight for a considerable distance above the bridge; and when there is a contraction in the channel at a little distance below the bridge, it renders the effects of floods less dangerous.

The situation being fixed upon, a correct section should be made of the bed of the river, showing the form of the opposite banks, and the depth of water at different seasons of the year. Also on this section should be put the line of the highest and lowest water marks, which should be drawn from the best information to be procured from the observations of the oldest inhabitants of the neighbourhood.

The nature of the bed of the river should be carefully examined, particularly in the site of the abutments or piers, by boring, driving in a rod of iron, or other means, and to a sufficient depth to be certain of the quality of the ground.

It would also be desirable to have a section showing the declivity of the bed of the river for a considerable distance above and below the situation of the intended bridge, and also the velocity of the stream at different periods.

### *The Width of the Bridge.*

241. The width of a bridge depends wholly on the situation of the place where it is to be erected. It ought to be wide in proportion to the importance of the communication to be effected, and according to the population of the place where it is at, or near; but it is desirable that its width should not be greater than its situation requires, because it increases the expense of erection without adding to its utility.

The width of a bridge between the parapets that is intended for wheeled carriages

may be from 18* to 45 feet, according to the situation. Where the road is at a distance from any principal town, and has little traffic upon it, the width of the bridge may be from 18 to 20 feet; in more frequented places, from 20 to 22 feet; near to towns, and on great public roads, from 25 to 30 feet; and in or near large cities, from 30 to 45 feet.

In private roads and parks they are made from 12 to 20 feet in width; and foot bridges, from 5 to 8 feet.

*On the Water-way that ought to be left for the River.*

242. The water-way of a bridge should be sufficient to give free passage to the highest floods, and particular regard must be had to this circumstance in fixing the height and width of the arches.

The form and quantity of water-way is often so much altered by the bulk of the piers, that there is an increase of velocity in the current under the bridge; and when the bottom is of such a nature that it will yield to this increased action of the current, there is much danger of the bases of the piers being undermined; also in navigable rivers it renders the navigation difficult and often dangerous. Whereas, if the forms and magnitudes of the piers be so contrived that there shall be only a very small increase of velocity under the bridge, those evils will be avoided, and the floods will pass without doing any material injury.

Whenever the velocity is increased by contracting the width of the stream, the bottom wears deeper, unless it be so hard as to resist the increased action of the current. In the latter case the chief evil will be the fall of water under the arch.

The velocity of rivers is extremely variable; it depends chiefly on the declivity of the bed, and is most considerable in mountainous countries. In level districts there is little to be apprehended from the effect of the velocity; nevertheless it would not be prudent, even in level situations, to contract the water-way so as to produce a rapid fall under the bridge, particularly if the bed of the river be not sufficiently firm to withstand it.

The danger of a considerable fall under the bridge is well known, from the bad construction of London Bridge, where the fall during the ebb is generally about 4 feet; and many lives have been lost in attempting to pass it. The want of a sufficient water-way appears to have been one of the causes, if not the chief cause, of the failure

* Smeaton says, that it is found by experience that 18 feet clear width admits of carriages passing with ease, freedom, and safety. Reports, vol. iii. p. 51.

of Hexham Bridge, in which the fall was not less than 5 feet at the time the bridge fell *, and the bottom not of a nature to withstand such an increase of velocity.

A bridge seldom if ever fails unless in consequence of a want of water-way; and, on the other hand, care should be taken not to run into the other extreme, as it is equally dangerous; because, when more space is left than is necessary, a deposit takes place of sand and gravel, which, when once begun, in process of time reduces the water-way so much as not to allow a free passage to floods.

243. The following table will enable the reader to compare the firmness of bottoms of different materials. The experiments were made by Dubuat †. The second column gives the greatest velocity the material in the third column is capable of resisting; and the fourth column contains the specific gravity of the material. In the first column the popular stages of accumulation are stated.

| Stages of accumulation termed. | Velocity of river in feet per second. | Nature of the bottom which just bears such velocities. | Specific gravity of the material. |
|---|---|---|---|
| Ordinary floods .... | 3·2 | Angular stones, the size of a hen's egg | 2·25 |
| | 2·17 | Rounded pebbles, 10 inches diameter. | 2·614 |
| Uniform tenors .... | 1·07 | Gravel of the size of garden beans ... | 2·545 |
| | 0·62 | Gravel of the size of peas .......... | 2·545 |
| | 0·71 | Coarse yellow sand ................ | 2·36 |
| Gliding .......... | 0·351 | Sand, the grains the size of aniseeds.. | 2·545 |
| Dull ............ | 0·26 | Brown potter's clay ................ | 2·64 |

244. It appears then, that the velocity of the water under the bridge is determined either by the nature of the bed of the river, or by the quantity of fall that would be hurtful to navigation.

If $b$ represent the breadth of the natural water-way, and $c$ the breadth as reduced by the construction of the bridge; also V the velocity in feet per second of the river in its natural state; then the velocity $v$ under the bridge will be expressed by the equation $v=m.V\frac{b}{c}$, and $c=m.b\frac{V}{v}$. Where $m$ is a constant quantity which expresses the contraction a fluid suffers in passing through a narrow passage. According to Sir Isaac Newton's experiments, the value of $m$ is $\frac{25}{21}$ ‡; this value of $m$ should be used when the ends of the piers are square; but they are generally made of a form better adapted for

* Smeaton's Reports, vol. iii. p. 338. It appears that the bottom was sufficient to withstand a fall of 3 feet 9 inches, but failed in the flood which rose to 5 feet. Page 313.

† Principes d'Hydraulique, tome ii. art. 399.

‡ Principles of Natural Philosophy, book ii. prop. 36.

dividing the stream; and Dubuat has made some experiments with models of piers with the end facing the stream in the form of an equilateral triangle, and according to these experiments we may take $m=1{\cdot}09$ *. Adopting this value, $v=1{\cdot}09\,V\frac{b}{c}$, and $c=1{\cdot}09\,b\frac{V}{v}$.

*Example.* Let the bottom of the river be fine sand, and the breadth of the natural water-way 36 feet, and the velocity $V=0{\cdot}25$ feet per second. Then for a fine sandy bottom, $v$ should not exceed 0·351 feet; hence $c=1{\cdot}09\,b\frac{V}{v}=\frac{1{\cdot}09\times36\times0{\cdot}25}{0{\cdot}351}=27{\cdot}7$ nearly, which is the breadth of the contracted water-way; and 8·3 feet may be occupied with piers without endangering the bottom.

245. Retaining the same notation, the quantity of fall, $h$, will be found by the equation $\frac{m^2b^2-c^2}{64c^2}\times V^2=h$ †. And taking the value of $m=1{\cdot}09$, then $m^2=1{\cdot}1881$; or near enough for practice, $m^2=1{\cdot}2$; consequently, $\frac{1{\cdot}2b^2-c^2}{64c^2}\times V^2=h$, the fall.

*Example.* The breadth of the Thames above London Bridge is about 936 feet, according to the observations of Mr. Labelye, in 1746; and the sum of the water-ways at the time of low water is about 200 feet; the mean velocity of the stream just above the bridge $3\frac{1}{6}$ feet per second. Therefore $\frac{1{\cdot}2b^2-c^2}{64c^2}\times V^2=\frac{1{\cdot}2\times876996-40000}{64\times40000}\times\frac{361}{36}=\frac{1011315{\cdot}2}{2560000}\times\frac{361}{36}=3{\cdot}96$ feet, or 4 feet nearly; which renders the passage extremely dangerous.

The velocity of the current and the area of the section should be ascertained at the time of the highest floods; but as this is seldom possible, we must often be satisfied with an approximate value of the fall at that time; which may be obtained by observing the velocity when the river is as much above its ordinary height as it may happen to be during the time allotted for observation, and ascertain the depth of the river corresponding to that velocity. Now in the same river and situation the velocity is nearly as the square root of the depth; therefore the velocity for one depth being known, that for any other depth may be found by direct proportion.

The fall under the bridge is directly as the square of the velocity, therefore there is much danger in contracting the water-way of a rapid river, and the fall will also be

* Dubuat's lowest number is 1·097, but in wide rivers perhaps it will be less; therefore I have assumed 1·09 as near the truth. See Dubuat's Principes d'Hydraulique, tome i. p. 15.

† An investigation of this formulæ is given by Dr. C. Hutton, in his Tracts, vol. i. p. 87, or vol. iii. p. 371; also in his Course of Mathematics, vol. iii. p. 378.

nearly as the depth of the river; which shows how necessary it is to ascertain the height of the highest floods*.

246. The following is a table showing the velocities of some of the principal rivers, which may assist in giving more accurate ideas on this interesting subject; and we have only to regret that so few observations have been made that it is not so complete as it might have been expected.

| Name of river. | Place of observation. | State of river. | Velocity in feet per second. | Observer. |
|---|---|---|---|---|
| Thames . . . | Above London Bridge . . . . . . . . . | Mean state | 3·1667 | Labelye. |
| | Above Westminster Bridge . . . . . | Mean state | 2·25 | Labelye. |
| Seine . . . . . | Between Tuileries and Pont-neuf | | 1·54 | Marriotte. |
| | Between Surène and Neuilly . . . . | | 2·55 | Chézy. |
| Tiber . . . . . | Rome . . . . . . . . . . . . . . . . . . . . . . . | Low water | 3·28 | |
| Danube . . . . | Ebersdoff . . . . . . . . . . . . . . . . . . . . | Low water | 3·45 | |
| | | High water | from 7·2 to 12·2 | |
| Loire . . . . . | Declivity of the bed ·000382 . . . . | | 4·25 | |
| Rhone . . . . | At Arless . . . . . . . . . . . . . . . . . . . . | Low water | 4·8 | |
| | At Beaucaire . . . . . . . . . . . . . . . . . | Low water | 8·2 | |
| Durance . . . | From Sisternon to its mouth . . . . | Mean state | 8·2 | |

In 1818 an immense collection of water was collected in the Val de Bagnes, in Switzerland, by a glacier sliding into the valley; when the ice gave way, the torrent burst forth with the tremendous velocity of 33 feet per second, and swept two bridges away in its course, and still retained a velocity of 6 feet per second, when it flowed into the Lake of Geneva, a distance of nearly five miles†.

## *Of the Span of the Arches.*

247. The extent of the span is the next subject to be considered; it will be obvious that this is in some degree determined by what has been said respecting the quantity of water-way. The span of the arch, however, must also be regulated by the form of the banks; the height of the highest floods, the depth and rapidity of the river, and the kind and dimensions of the timber that can be procured.

* Respecting the velocity of rivers, and the fall of water under bridges, the reader may consult Dubuat's Principes d'Hydraulique, edit. 1816; Dr. Robison's article River, Encyclopædia Britannica; Playfair's Outlines of Natural Philosophy, vol. i. p. 190; Rees's Cyclopædia, art. River, by Mr. John Farey, Jun.; Hutton's Tracts, vol. i.; Sir H. Douglass on Military Bridges; and Dr. Brewster's Encyclopædia, art. Hydrodynamics.

† Edinburgh Philosophical Journal, No. 1, p. 191.

In rivers that are tranquil, of little depth, and not subject to high and rapid floods, the number of piers may be augmented without inconvenience, provided they do not interrupt the navigation of the river, nor contract too much the water-way.

But if the bridge have to cross a torrent, the least possible number of supports should be placed in the stream. When the banks are not too low, and the width of the river does not exceed 300 feet, the engineer should give the preference to one arch. When more than one arch is required, much expense cannot be saved by making the span of the arches large, because the piers in such cases require to be carefully constructed, and there will be much additional labour, and consequently expense, both in the arches and piers. But if the opening be not greater than can be spanned with one arch, it would certainly be the best method to do it so, especially if the banks be high on each side.

248. The rise of the arch or arches is generally limited by the form of the roadway, and the height of the highest water line, as that line should be the springing of the arch. The roadway should always be of as easy an ascent as circumstances will admit of; ascending from each side to the middle in a rise of about one part in 36, gives the bridge a slight curvature, which improves its appearance; but it ought not to rise at a quicker rate than one part in 12. On this subject Mr. Smeaton remarks, that the ascent of Westminster Bridge was originally laid out to be one part in 20, but he apprehends it to be at least one in 12; and further observes, that it is a kind of rule in laying out roads and bridges, "if the ascents do not exceed 3 inches per yard, they are no ways objectionable*."

Holborn Hill is stated to have a rise of one in 18, and that it is necessary at all times to lock the wheel of a loaded waggon. Ludgate Hill rises only one in 36†; and when it is possible to construct a bridge with so gentle a rise it is much more desirable. Mr. Telford mentions one in 24 as a convenient ascent for a bridge ‡; and it is perhaps that which will in general be found to agree best with the other circumstances to be attended to in the erection of a bridge.

Mr. Wiebeking § also names a rise of one in 24 as that which may be used without inconvenience; but he observes, that, in timber bridges, the settlement is generally about one part in 72; that is, if a timber bridge of 144 feet span rise one foot in the middle when first framed, it will settle so as to become nearly horizontal; therefore, when it is intended that the bridge shall have an ascent of one in 24 when finished, it must be framed so as to have a rise of one in 18; for $\frac{1}{18}=\frac{1}{24}+\frac{1}{72}$.

* Smeaton's Reports, vol. iii. p. 226.

† Supp. to Ency. Brit. art. Bridge, p. 507.

‡ Edinburgh Ency. art. Bridge.

§ Traité d'une Partie Essentielle, &c; p. 125.

249. But when the rise of an arch or truss is limited, whether it be by the form of the roadway or any other local circumstance, the span is also limited; for if the span does not bear a certain proportion to the rise, the bridge will not support its own weight. This proportion depends on the radius of curvature of the curve of equilibrium, and from the length of this radius we may also determine to what extent a single arch may be constructed. The largest span that we have any correct account of being executed with timber is the bridge over the Limmat, near Wettingen, of which the span was 390 feet, the whole rise about 43 feet, and the radius of curvature of the curve of equilibrium about 600 feet.

It has been found by experiment that the force required to crush a square inch of oak is 5147 pounds*, and suppose one-fifth of this force to be a sufficient load to trust upon each square inch in a bridge, this force would be equivalent to the weight of a column of the same material 2950 feet high. And it is shown by writers on the strength of materials, that in an arch of the same material, of which the radius of curvature is equal to the height of this column, the parts of the arch will be pressed with the same force as the weight of the column.

Consequently, in a bridge constructed of oak, the radius of curvature should never exceed 2950 feet; and for fir it should not exceed 3000 feet.

But when the construction is similar to a framed lever; the abutments being secured by a horizontal tie, the radius of curvature of the curve of equilibrium of the compressed part of the frame, when it is sufficiently loaded with its own weight, will be only half the height of the column that would produce an equal pressure on the same base, because in this kind of construction there is at least double the weight of materials. Therefore, in a bridge with horizontal ties the radius of curvature should not exceed for oak 1475 feet, for fir 1500 feet.

These numbers only give the radius when the frames, or ribs, are sufficiently loaded with their own weight; but there is the roadway and the timbers connected with it, which add nothing to the strength of the bridge. But the radius of curvature of a bridge that will be sufficiently loaded when the whole weight to be laid upon it is taken into consideration, may be found by the following proportion:

As the whole weight of the bridge,
Is to the weight of the supporting frame;
So is the radius of curvature above determined,
To the radius required.

The following table shows the radius of curvature when the weight of the supporting frame is to the weight of the whole in the ratios at the head of the columns.

* Philosophical Transactions for 1818; or Philosophical Magazine, vol. liii. p. 170.

| Kind of construction. | Radius of curvature. | | | |
|---|---|---|---|---|
| | Weight of roadway, &c. 5 / Weight of frame .... 1 | Roadway, &c. . 6 / Frame ...... 1 | Roadway, &c. . 8 / Frame ...... 1 | Roadway, &c. 10 / Frame ..... 1 |
| | feet. | feet. | feet. | feet. |
| Curved ribs of oak supported by abutments | 590 | 422 | 330 | 270 |
| Ditto of fir, ditto ...... | 600 | 430 | 334 | 273 |
| Framed with horizontal tie, oak .......... | 492 | 370 | 295 | 246 |
| Ditto, fir .............. | 500 | 375 | 300 | 250 |

These calculations suppose the parts of the bridge to be accurately balanced, according to the principles of equilibrium; and it is obvious, that any defect in this respect must render it necessary to increase the curvature.

Wiebeking, in his work on Bridges, gives some proportions for the rises for different spans, but not from principle; his proportions being founded entirely upon the observations he had made in practice. As far as regards appearance, he states one-tenth of the span to be the best proportion for the rise of an arch; but as it is in general desirable to keep bridges low, he gives the following proportions:

From 100 to 150 feet span make the rise $\frac{1}{20}$
200 .................... $\frac{1}{18}$
300 .................... $\frac{1}{15}$
400 .................... $\frac{1}{14}$
500 .................... $\frac{1}{13}$
600 .................... $\frac{1}{12}$

Wiebeking says, that experience had convinced him that larger spans require a greater rise than small ones*; but it will be seen from a table I have given in art. 270, that large spans require even a greater rise than he has assigned to them; indeed, his proportions are not to be depended upon beyond 300 feet spans, nearly so far he has had experience: and to determine the least rise for larger spans, the rules I have laid before the reader, or others derived from the same principles, are the only ones to be depended upon.

It is of considerable importance to know the radius of curvature that should not be exceeded for different materials, as it determines at once the least rise that ought to be given to an arch when the span is known, as well as the extent of span when the rise is known. Perhaps the young artist may imagine that I have undervalued the

* Wiebeking's Traité d'une Partie Essentielle, &c. p. 126 and 127.

strength of the materials in taking only one-fifth of the force that actually produced fracture, but he must remember that when fracture takes place the piece submitted to experiment is generally shortened about one-third of its length; now, as the quantity of compression is as the force nearly, one-fifth of the force would reduce the length almost one-fifteenth part, which would produce a degree of derangement in a system of framing that should never be found in a bridge.

### *Construction of the Abutments and Piers.*

250. The abutments and also the piers should be executed in stone, in which case all that relates to the construction of them falls within the mason's department; nevertheless, as they should be capable of sustaining the thrust of the arch where there is not a horizontal tie, I have given the following rule for finding the proper thickness; the abutments being rectangular, and the weight of a cubic foot of the stone-work 120 pounds.

RULE. Multiply the square of the height of the abutment by 160, and divide this product by the weight of a square foot of the arch, and by the rise of the arch; add unity to the quotient, and extract the square root.

Diminish the square root by unity, and multiply the root, so diminished, by half the span of the arch, and by the weight of a square foot of the arch.

Divide the last product by 120 times the height of the abutment, and the quotient will be the thickness of the abutment.

*Example.* Let the height of the abutment from the base to the springing of the arch be 20 feet, half the span 100 feet, the weight of a square foot of the arch, including the greatest probable load upon it, 300 pounds, and the rise of the arch 18 feet. Then $\frac{160\times20\times20}{300\times18}=11{\cdot}852$, and $11{\cdot}852+1=12{\cdot}852$. The square root of $12{\cdot}852$ is $3{\cdot}6$ nearly; and $3{\cdot}6-1=2{\cdot}6$. Also $\frac{2{\cdot}6\times100\times300}{120\times20}=32{\cdot}5$ feet, the thickness required.

The abutment thus determined is one-fourth above what would barely resist the thrust of the arch, besides the additional stability it receives from that part of the height above the springing. In order to prevent any risk of sliding at any of the joints of the masonry, it would be an advantage to incline them towards the opening of the arch, making the inclination less and less as it approaches the base. In *fig.* 112 and 114, the joints are drawn in the manner proposed.

### *Piers.*

251. When piers are necessary, either to save expense, or to reduce the span of the arches to a practicable extent, to construct them of stone is the best method, as piers of timber very rapidly decay: the timber in a wooden pier being exposed to the alternate action of dryness and moisture, and consequently in the worst situation timber can be placed in.

Stone piers for wooden bridges have been used in many situations: the following table shows the span of the arches and thickness of the piers in some of the principal ones.

| Name of bridge, &c. | Span of centre arch. | | Thickness of piers. | | Thickness of pier in parts of span. |
|---|---|---|---|---|---|
| | feet. | inches. | feet. | inches. | |
| Bridge over the Schuylkill, at Philadelphia * | 194 | 10 | 27 | 7 | $\frac{1}{7}$ |
| Bridge at Trenton, over the Delaware * .... | 194 | 0 | 19 | 0 | $\frac{1}{10}$ |
| Bridge of Tournus, over the Saone, France † | 89 | 6 | 16 | 6 | $\frac{2}{11}$ |
| Bridge of Choisy, over the Seine, France † .. | 67 | 6 | 9 | 10 | $\frac{1}{7}$ |

It will be seen that considerable latitude has been taken in fixing the dimensions of stone piers. If it be considered that they should be capable of withstanding the thrust of the arches, their thickness should be found by the same rule as has been given for the abutments. The ends of stone piers should be of a parabolic form, in order that the water may glide easily between them ‡.

252. When timber is used for piers, they may, in simple cases, be constructed by driving a single row of piles for each pier in a line with the current of the river. The piles may be from 10 to 14 inches square, and placed at from 2 to 4 feet distance from one another. The piles should be strengthened by oblique braces. *Fig.* 93, *Plate* XVI. represents a pier of this kind.

253. In a deep river, or where the height of the roadway is much above the surface of the water, it is difficult to get piles of sufficient length. In such a case the piles may be driven and cut off a little below low-water mark, and upon these piles posts may be placed for supporting the roadway. The joinings should be secured by means of horizontal pieces well bolted together. A, B, and C, *fig.* 117, *Plate* XX. show how the upper and lower parts of the pier should be connected.

The piers of the Bridge of St. Clair, at Lyons, are constructed nearly in this manner §,

* Quarterly Review, vol. xix. p. 256.

† Gauthey, Construction des Ponts, tome ii. p. 63 and 65.

‡ See Dubuat's Principes d'Hydraulique, tome i. p. 294.

§ Gauthey, Construction des Ponts, tome ii. p. 72.

and it has the advantage of giving good hold to the piles, besides rendering them much easier to drive; it also cuts off the connection between the part of the pier, which is constantly wet, and of long duration, and that which is alternately wet and dry; consequently it is much easier to repair or renew the posts which will from their situation often require it.

254. But when the depth of the river is very considerable, it would not be safe to trust to a single row of piles; in that case the lower part should consist of a double row of piles, BB (*fig.* 118, *Plate* XX.) at about three feet distance from middle to middle, connected by the horizontal beams EE, and the cross pieces DD, for supporting the posts.

In order to secure the feet of the posts they must be clasped by two horizontal ties, C, C, and the whole well bolted together.

*Fig.* 93, *Plate* XVI. and *fig.* 99, *Plate* XVII. show how the posts may be braced; and when their height is considerable, one or more courses of horizontal ties will be required besides the inclined braces.

255. Instead of driving piles for the piers or supports of a wooden bridge, Mr. Telford has adopted another method with perfect success on the river Severn, about eight miles below Shrewsbury. He makes choice of any convenient situation on the banks of the river for constructing the pier, which consists of an upright frame which has a grated frame attached so as to form its base, the base extending on each side of the upright frame. The framing is then sunk in its proper situation, the bottom having been carefully levelled to receive it.

Through the spaces in the grated frame short piles are driven to keep the whole secure in its place. The sides of the upright frame are covered with planking, and in order to add to the stability, the lower parts are filled with gravel and small stones.

To prevent ice, or other bodies carried down by the current, from injuring the piers, the edges of the frames which face the stream have triangular pieces of cast iron fixed upon them*. Fender piles are also sometimes driven so as to form a triangle at a little distance above and opposite to each pier.

256. When a river is subject to ice floods the piers should be protected by ice-breakers, which should be detached, in order that the bridge may not be injured by the shock of bodies descending with the current. The ice-breaker, A, B, *fig.* 98, *Plate* XVII. consists of a single row of piles, connected by two horizontal beams, with an inclined capping, the edge of which is protected by a triangular prism of cast iron.

*Fig.* 119, *Plate* XX. is a plan, and side elevation of an ice-breaker, consisting of two rows of inclined piles; the heads of which abut against an inclined capping, protected

* Edinburgh Encyclopædia, art. Bridge, p. 537.

with iron as before. The inclined sides to be covered with planking, which is not shown on the engraving.

In a large bridge there is little danger to be apprehended from connecting the ice-breaker with the pier.

257. Piles from 10 to 14 inches diameter require to be driven with a ram of from 1000 to 1700 pounds weight.

Pile planks require a ram from 500 to 900 pounds weight; and are about 8 or 9 inches wide, and 3 or 4 inches thick.

The Bridge of Freysingen, already described, art. 236, is an example of a timber pier of a different construction, which is well worthy of the reader's attention.

But after every precaution is taken to ensure the durability of wooden piers, they almost always are in a state of decay before the superior parts of the bridge; therefore they should only be used where it is difficult to procure stone: in such cases the modes of construction adopted by Mr. Telford and Mr. Wiebeking may be employed with advantage.

### *Construction of the Arches and Timber Frames for Wooden Bridges.*

258. Before proceeding to specify the modes of construction that are adapted to particular cases, a few observations on the general principles of construction will perhaps render the advantages of the methods I propose more evident, and, what is of more importance, will improve the reader's notions of the subject.

Let AB, *fig.* 100, *Plate* XVIII. be a solid beam resting upon the supports A and B. If we suppose this beam to be the support of a roadway, it will, besides its own weight, have to support the planking and road, as well as any heavy body moving over it. A beam may be made stronger, with the same quantity of timber, by making it deeper in the middle, and less at the ends, as in *fig.* 101; for a strain at C will have less effect in bending the beam than one at the middle of the length. Also, however the weight may be distributed, if it be sufficiently great it will cause the beam to bend; and when a beam bends, it is observed that the fibres at the upper side *d* are compressed; and that those on the lower side *e* are extended. Also, that there may be a line drawn at the middle of the depth *a c b*, where the fibres are neither extended nor compressed, but remain in their natural state. But all the fibres between *c* and *d* are compressed, and all those between *c* and *e* are stretched; but not equally so, because the nearer a fibre is to the points *d* or *e* the more it is strained. Now as the middle part of the depth of the beam is very little strained compared to the upper and lower sides, it is clear that we can employ the same quantity of timber in a more effectual manner, by using a beam that is deeper, and cutting out the middle, as is shown in

*fig.* 102. Because we have seen that the middle part exerts very little force, and its weight is a considerable load on the beam.

259. If we now attend to the forces that are exerted by the parts of the beam, it will be found that the upper part *a m d n b*, is wholly compressed in the direction of its length, and that the lower part, *a r e s b*, is wholly extended in the direction of its length; and it is well known that timber offers the greatest degree of resistance when strained in the direction of its length, when the necessary degree of security can be given to the joints.

260. From these considerations we are naturally led to the kind of construction shown by *fig.* 103, where it is obvious the same pressures obtain as in the perforated beam above described; the only difference is, that here the tie beam is supported, as otherwise it would fail in large spans. The celebrated bridges of Schaffhausen, Zurich, Landsberg, and Wettingen, are constructed on this principle. In the Bridge of Schaffhausen the disposition of the timbers is nearly the same as shown by *fig.* 103. The continued tie AB retaining, and being an abutment for the compressed beams, the frame requires only to be supported, and has no other thrust on the abutments of the bridge, than a solid beam would have. Framed bridges, such as that designed by Palladio, *fig.* 86, *Plate* XVI. may be referred to the same principle.

261. It is easy to conceive that the tie might be entirely removed, provided that the abutments were made capable of sustaining the thrust. This, without any other change, leads us to the kind of construction represented in *fig.* 104, which has been adopted by Joseph Ritter for a bridge across the torrent of Kandel, in the canton of Berne*. Mr. Semple has given a design for a bridge on this principle†.

262. But as long pieces of timber require to be of a proportionate depth and breadth, consequently are not easily procured, and in scarfing much of their strength is lost, a kind of construction where short timbers can be procured is desirable. *Fig.* 105 represents a combination which may be used in such cases with advantage. Such a combination has been often employed; we have an example in that of Palladio across the Brenta (see *Plate* XVI. *fig.* 88;) and the Bridge of St. Clair, over the Rhone, at Lyons, is of the same kind.

263. We cannot however derive much benefit from shortening the beams, by dividing the span into shorter lengths, because the angles of junction become more obtuse or open, and of course the strain in the direction of the pieces is much increased. And, however strong such a bridge might be in respect to a constant load distributed over it, the weight of any load moving upon it would soon derange it; because the strength of such a system to resist a variable load must depend wholly on the strength of the

* This bridge is described by Gauthey, Construction des Ponts, tome ii. p. 61; and also by Rondelet, l'Art de Bâtir, tome iii. p. 316.

† Semple on Building in Water, p. 114.

joinings, which it is difficult to give much strength to. Nevertheless bridges have been both designed and executed on such principles, as is represented by *fig.* 106 and 107. The combination, *fig.* 106, resembles the Bridge of Mulatiere, at Lyons, over the Saone*; and *fig.* 107 is combined in the same manner as the arches of the Bridge at Kingston, over the Thames, of which the span is 49 feet. The Bridge at Walton is nearly on the same principle, and was found in a state of decay in 20 years †; and the Bridge of Sault, on the Rhone, was also on the same principle as *fig.* 107, and failed within 13 years ‡.

264. From combinations of the kind last noticed, the continued curved rib, in the manner proposed by Price (see art. 232) naturally succeeds, which possesses advantages that are not to be found in a series of beams merely abutting end to end. For when the rib is built of short lengths, with the joints crossed, and the different thicknesses firmly bolted together, it becomes as one solid beam. If we suppose the straining force to be applied at D, *fig.* 108, then the force must be sufficient to fracture the rib at C, D, and E; therefore, when the strength of the rib is capable of sustaining the strains at C, D, and E (see Sect. II. art. 128) and the curve is a proper curve of equilibrium to the constant load (see Sect. I. art. 52;) this is at once a simple and effectual combination. The use of curved ribs of this kind, I have already noticed, appears to have been known at a very early period (Sect. VIII. art. 228;) but it has been only lately that they have been extensively employed in the construction of bridges, and it has been further improved by bending the pieces that form the ribs. Among other considerable structures on this principle may be noticed, in France, the Bridge of Choisy, on the Seine, and that of Chazey, on the Ain; the former 67 feet, and the latter 64 feet span; the Bridge of Tournus, on the Saone, built in 1801, of nearly 90 feet span: in Bavaria, a bridge near Oettingen, on the river Inn, built in 1807, of 103 feet span; the bridge near Freysingen, on the Isar, of 153 feet span, built in 1808; and the bridge near Bamberg, over the Regnitz, of 208 feet span, built in 1809. The last three were designed by Mr. Wiebeking §, and two of them are represented in *Plate* XVII. A rib composed of bent beams is shown by *fig.* 109.

It may not be altogether useless to remark, that cast-iron bridges are now constructed nearly on the same principle as *fig.* 108; the finest specimen that I have seen is the Southwark Bridge, consisting of three arches, the span of the centre arch being 236 feet. It was designed by Mr. Rennie ||.

265. As a bridge with a curved rib, when the span is considerable, yields at D, C, and

* Gauthey, Construction des Ponts, tome ii. p. 56.

† Smeaton's Reports, vol. iii. p. 371. An engraving of Walton Bridge, from a drawing by Mr. John Farey, is given in Rees's Cyclopædia.

§ Gauthey, Construction des Ponts, tome ii. p. 55.

‡ Idem, tome ii. chap. ii. sect 1.

|| The Southwark Bridge is described in the Supplement to the Encyclopædia Britannica, art. Bridge, plate xliii.

E (*fig.* 109) when the load is applied at the middle, the strength must of course be increased, by increasing the depth of the rib; and consequently, a framed rib, such as is shown by *fig.* 110, is the next step in the progress of improvement. Here however it must be observed, that the two curved ribs must be continuous, and put together so as to resist either extension or compression, as in *fig.* 109. For when a load is placed at D, the lower rib will be extended at *d*, and compressed at C and E; while the upper one will be compressed at D, and extended at *c* and *e*. And a weight applied at any other point would produce a similar effect.

When the span becomes so great that two curved ribs can be introduced without being made smaller than is required for the firm connection of the parts of each rib, then framed ribs would be a vast addition to the stability of the bridge. Many designs bear a near resemblance to the kind of construction now under consideration, such, for example, as that by Palladio (*Plate* XVI. *fig.* 87*;) but it is clear that such designs possess no other advantage than framed voussoirs, and they are well adapted for iron bridges where firm connection cannot have place without endangering the structure, in consequence of the expansion of the material.

In timber, however, where we have nothing to fear from expansion, it is losing one of the greatest advantages of the material to interrupt the connection of the parts; besides many joints should always be avoided, both on account of the difficulty of making them fit, so as to bring every part alike into action, and also of the difficulty of preventing decay at such joinings.

In some cases it is difficult to form abutments, and also desirable to keep the roadway as low as possible; in such cases *fig.* 111 shows a kind of construction that may be used. It is peculiarly adapted to a situation where the banks of the river are low, and where there is no navigation to interrupt. Where the width of the bridge is considerable, a rib may rise in the middle of the width, so as to divide the roadway into two parts. Sometimes a double rib might be placed in the middle, with a footway between. But where there is much attention paid to architectural effect, bridges with framing to rise above the roadway will seldom be adopted.

As cross ties will be necessary at the top, the middle parts might be covered with a roof to protect them; also a continued coping, *a a*, *a′a′*, might be put over each truss, which would improve the appearance, as well as protect the framing.

266. I have now noticed each of the simple combinations, and if I have been successful in showing the general principles of forming such combinations, the carpenter will find it easy to span any opening within the limits I have pointed out in art. 249 of this Section.

When the distance of the abutments, or piers, does not exceed 16 feet, a bridge may be constructed by simply laying beams across the opening of about 15 inches deep, by

* Leoni's Palladio, plate vi.

8 inches in breadth, and about 2 feet apart. For foot bridges this kind of construction may be extended to 18 feet, with the same scantlings. When the extent of bearing for a bridge for carriages does not exceed 35 feet, the kind of bridge shown by *fig.* 88, *Plate* XVI. may be adopted. When there are more openings than one, any of these simple forms might be much strengthened by continuing the beams over more than one opening when the timber is long enough; and when it is not, to scarf the beams together at the points of support. Also, short pieces of timber may be placed under each beam, extending from 5 to 7 feet on each side of the cap of the pier, as at AA, *fig.* 88. The Bridge of Bassano is here given as an example of this kind of construction.

The strength is sometimes further increased by trussing the railing on each side of the roadway. A foot bridge, designed by Mr. P. Nicholson, is a very good model*, and is peculiarly well adapted for any situation where lightness of appearance is desirable.

267. As it has been shown that curved ribs are preferable to other methods of spanning a wide opening, it will only be necessary to select two or three cases as examples. If the span is not more than 50 feet, each rib may be composed of two or three thicknesses of planks of a convenient length, bolted together, and the joints crossed; one of three thicknesses is preferable. The ribs should rise as much as an attention to the form of the roadway and other circumstances will allow of; and they should be about from 6 to 9 feet apart, with the roadway supported by upright pieces in pairs, notched and bolted to the ribs. As the weight of the roadway presses in a vertical direction, and it may be considered as a general principle, that each piece (when possible) should be placed in the same direction as the force acts in that it is intended to sustain; therefore the reason for placing them upright is evident. The distance of the upright pieces should never exceed 15 feet, and horizontal cross ties should be placed at the same points, with diagonal braces, to prevent the bridge from vibrating sideways when heavy loads are moving over it. Diagonal pieces should also be inserted between the road timbers, as lateral motion should as far as possible be prevented.

268. In larger spans, that is, in spans exceeding 50 feet, there will be difficulty in obtaining timber deep enough for the ribs; therefore they should be built the contrary way, and bent to the required curve, so as to increase the depth. The beams forming the ribs should be scarfed at the joinings; the form of the scarf should be such as would resist either pressure or tension (see Sect. IX. art. 295) and the scarfs should be kept as distant from one another as possible. The number of thicknesses in each rib must depend on the size required for the span, and the dimensions of the timber that can be procured; and the whole should be well bolted together. The supports of the roadway and diagonal braces to be placed as described in the last article.

* Nicholson's Architectural Dictionary, plate i. of Wooden Bridges.

*Fig.* 112, *Plate* XIX. represents a bridge designed for a 200 feet span; *fig.* 113 is a section across at CD to a larger scale. This bridge is sustained by four ribs, each rib 18 inches thick and 4 feet deep. The ribs to be two thicknesses in width, and either three or four in depth, according to the size of the timber: the lengths of timber should be disposed so as to cross the joints as much as possible, and the joints should be scarfed. One of the most simple scarfs will be the best adapted for that purpose. The pieces composing a rib must be well bolted together, and keys in the joints would be a further means of preventing any sliding of the parts.

The vertical pieces which support the roadway are intended to be put on in pairs, notched to the rib, and bolted together, and not more than 18 feet apart. And at each pair a double tie is intended to cross both the back and the under side of the ribs, notched on to the ribs and bolted to the vertical pieces.

Between the timbers which carry the joists of the roadway diagonal braces should be framed so as to secure the bridge from lateral motion. A series of braces for the same purpose might be framed over the back of the ribs; but one of these methods, if well executed, will be sufficient.

The bridge is intended for a gravel or paved roadway, and is calculated to sustain two loaded waggons at its weakest point without injury.

This kind of bridge is adapted to any span that is usual in bridge building, the ribs not to exceed about 8 feet apart, and their dimensions may be easily calculated for any span by the help of art. 274 and 275 of this Section, and art. 128 of Sect. II.

As the beams are intended to be bent to the form of the rib, it will be prudent to ascertain whether such a degree of curvature may be given to the beams without impairing their elastic force. The curvature to be given to the beams will be sensibly uniform, and the degree of uniform curvature that may be given to a beam is inversely as its depth, or the radius of curvature will be directly as the depth. But it has been shown by Dr. Young, that the deflexion of a beam uniformly curved is to that of one bent, by a load placed in the middle of its length, as 3 is to 2*; and as Mr. Barlow has determined the degree a beam will bend without destroying its elasticity by experiment†; on these data a rule for the depth of the beams for a curved rib may be established.

Let $x$ be the deflexion found by experiment, upon a beam, of which half the length is $y$; then $\frac{3x}{2}$ will be the deflexion corresponding to an uniform curvature; and $\frac{y^2}{3x}$ = the radius of curvature, the deflexion being small when compared with the length.

If the depth of the beam employed for experiment be $d$, and R the radius of

* Lectures on Natural Philosophy, vol. ii. art. 325.

† Essay on the Strength of Timber, Tables, p. 180.

curvature of the bridge, we have $\frac{y^2}{3x} : \mathrm{R} :: d : \frac{3xd\mathrm{R}}{y^2}$ = the depth of the beams that may be employed for the curved ribs.

Hence, from Mr. Barlow's experiments, we have

For English oak, ·05 R = the depth of the beam in inches.
For Riga fir, .. ·035 R = the depth of the beam in inches.
For larch, .... ·077 R = the depth of the beam in inches.

Mr. Wiebeking has made some experiments on bending beams on a very large scale, which tend to prove the correctness of the method I have used in finding the depth. He observed, that when several pieces were placed one upon another they would curve much more without fracture than a single piece would do*.

The radius of curvature of the Bridge of Bamberg was 422 feet and 422 × ·035 = 14·77 inches. The depths of the beams employed were from 13·5 to 15·5 (see Table, art. 238;) the depth given by my rule is nearly a mean between those that were used.

269. If the span be greater than 250 feet, instead of single curved ribs it would be an advantage to make frames each consisting of two curved ribs, with radial pieces, and crosses between, as shown in *fig.* 114, *Plate* XIX. The ribs should be formed as described in the last article. The radial pieces should be notched on to the ribs, in pairs, and bolted together; the diagonal pieces, or crosses, halved together in the middle, and made to abut end to end between the radial pieces. See *fig.* 115 and 116. *Fig.* 115 shows a plan of the framing; and *fig.* 116 a section across at the middle.

At AB, *fig.* 114, horizontal ties are notched and bolted to the vertical supports, so as to brace them in both directions; and a series of diagonal braces might be applied upon the horizontal cross ties, which would be very effectual in stiffening the bridge against lateral motion.

The braces shown by dotted lines in *fig.* 116 need be applied only at 4 or 5 places in the whole length of the bridge. The roadway to be formed and supported as in the preceding examples.

270. The rise of the curve should never be less than that determined by the equation $\frac{s^2}{2\sqrt{h^2-s^2}} = r$ = the rise of the curve, of which $s$ is half the span, and $h$ is the height of a column of matter which would produce the same pressure upon its base as the greatest pressure that ought to be transmitted through the framing. In large arches the ratio of the weight of the supporting frame will be to that of the part supported in general nearly as 1 to 6, and in small spans, as 1 to 10; whence the reduced value of $h$ will be, for timber, about from 430 feet to 270 feet. The following table shows the least rise corresponding to each span, which will be more convenient for use than the one given in art. 249.

* Traité contenant une Partie Essentielle, &c. p. 123.

*Table of the least Rise for different Spans.*

| Span in feet. | Least rise in feet. | Span in feet. | Least rise in feet. | Span in feet. | Least rise in feet. |
|---|---|---|---|---|---|
| 30 | 0·5 | 120 | 7 | 280 | 24 |
| 40 | 0·8 | 140 | 8 | 300 | 28 |
| 50 | 1·4 | 160 | 10 | 320 | 32 |
| 60 | 2 | 180 | 11 | 350 | 39 |
| 70 | $2\frac{1}{2}$ | 200 | 12 | 380 | 47 |
| 80 | 3 | 220 | 14 | 400 | 53 |
| 90 | 4 | 240 | 17 | | |
| 100 | 5 | 260 | 20 | | |

It must be remembered, that a small rise should be avoided, if possible, because it requires a much greater quantity of timber to make the bridge equally strong.

271. The proper curve of equilibrium should be found by the principles laid down in Sect. I. art. 56 to art. 61. But in general it will differ very little from the common parabola, which is easily described. (See Sect. IV. art. 171.)

Wooden bridges, however well they may be executed, will always settle a little immediately after construction, and this will increase in a small degree with time. Mr. Wiebeking has made some observations on this subject, and has found that the settlement in the middle may be expressed in inches by $\cdot 806\frac{r}{s}$, where $r$ is the rise in feet, and $s$ the whole of the span in feet*.

## *Of the Roadway.*

272. The roadways of bridges are constructed in various ways, but the most usual one is to pave upon gravel; sometimes gravel only is used, and some prefer planking only.

The planking in small bridges is often laid immediately upon the principal beams, which, in such cases, are placed about two feet apart, as in *fig.* 99, *Plate* XVII.; but it is better in respect to durability to lay cross joisting for supporting the planking; these joists should be about two feet apart, and the planking laid upon them, which may be from 3 to 4 inches thick. The cross joists admit the air to circulate more freely round the principal timbers, and therefore render them more durable. *Fig.* 113 and 116, *Plate* XIX. show the latter of these modes of construction.

* Traité contenant une Partie Essentielle, &c. p. 125.

Where bridges are intended for wheel carriages there should be a separate footpath; which may be paved with flag-stones. Footpaths are made from 3 feet to 6 feet wide, according to the number of the passengers. The carriage-way may be paved upon a bed of gravel of about 12 inches in depth. The paving to rise in a curve across the road. The gravel should contain a considerable portion of tempered clay, so as to bind it firmly together; but if there be too much clay, it will shrink and crack in drying. Belidor states, that paved bridges are the most durable*.

If the road-way should be only gravelled, the gravel should be from 12 to 18 inches deep in the middle, and from 9 to 14 inches deep at the sides, according to the traffic over the bridge. Whether the roadway be paved or gravelled, the means of conveying off the water should be provided.

As the moisture which passes through the gravel soon rots the planking, it is supposed to be better to lay an additional thickness of planking, and no gravel or paving. In that case the upper planking should lay across the bridge to prevent the feet of horses sliding. It would be easy to renew such a roadway, but I do not see any other advantage it possesses.

Parapets or ballustrades are made from 3·5 feet to 6 feet in height above the footpath; 4 feet is enough for protection. The railing is stayed by braces on the outside. Iron railing is sometimes used.

The railing should however partake of the character of the surrounding scenery. In towns, upright or diagonal bars and other ornamental railing may be used; but in all cases where trees and cottages form the most striking features of the surrounding landscape, simple horizontal rails with posts are preferable. Nothing is more formal and stiff than ornamental or upright railing, and nothing more picturesque than the simple continuous lines of horizontal rails.

Wooden bridges are often covered with a roof. The bridges of Schaffhausen, Wettingen, Kandel, Mellingen, and various others, were roofed. The roof does not appear to be of much service in protecting the bridge, and in later bridges it has been generally omitted. The planking of the roadway might be protected very much by a coat of pitch, tar, and sand. See Sect. X. art. 354. A composition of this kind was used for covering the planking under the roadway of the iron bridge, over the Wear, at Sunderland.

*On determining the Scantlings of the Timbers for Bridges.*

273. The greatest load that is likely to rest upon a bridge at one time would be that produced by its being covered with people. Such a load, together with the weight of

* Science des Ingénieurs, p. 364, edit. 1814.

the framing and gravelled roadway, would be about 300 pounds on a superficial foot, or 0·14 of a ton. And as this load may be supposed to be uniformly diffused over the bridge, half the load upon it will be expressed in tons by $0{\cdot}14w\times s$, where $s$=half the span, and $w$ is equal the width of the bridge.

If the bridge be only planked without gravel, as a foot-bridge, the greatest probable load will be expressed in tons by $0{\cdot}09w\times s$.

Now as the load is sensibly uniform, the curve of equilibrium will be a common parabola; and when the rib is of this form, any uniform load would have no tendency to produce any derangement or other strain in the rib than that which is propagated in the direction of the curve. Therefore the first object must be to determine the size of the ribs, so that they may be capable of resisting this pressure without being more compressed than is consistent with the stability of the structure.

Riga timber suffers a compression in direction of its length of about one fifteen hundredth part of its length under a load of 64 tons upon a square foot; and oak bears about the same load with the same degree of compression. Under such a pressure the curved rib of a bridge 200 feet in length would shorten rather more than 1·6 inches: and as it is a material that soon decays, this will not appear too low an estimate of its strength.

The pressure in a bridge increases towards the abutment; but it is advisable to increase the depth of the rib at the abutment, therefore we may estimate the pressure at the crown, which simplifies the operation.

The pressure in the direction of the rib at the crown is the same as the horizontal thrust, and may be determined by art. 40, Sect. I.; but it is more convenient for the present purpose to express it in a different manner.

If $x$ be the rise, and $s$ half the span; then, by the resolution of forces, $2x : s ::$ weight : to the pressure in the direction of the curve at the vertex or crown.

Therefore $\dfrac{0{\cdot}14w\times s^2}{2x}$=the pressure in bridges with gravelled roadways. (A.)

And $\dfrac{0{\cdot}09w\times s^2}{2x}$=the pressure in bridges without gravel or paving. (B.)

Also, if $b$=the breadth of each rib, and $d$=the depth of each rib, also $n$=the number of ribs; then $64n\times b\times d$=pressure, when the ribs are sufficiently strong.

Hence from equation (A) we have $\dfrac{0{\cdot}14w\times s^2}{2\times 64\times x\times n}=b\times d$. (C.)

And from equation (B) we have $\dfrac{0{\cdot}09w\times s^2}{2\times 64\times x\times n}=b\times d$. (D.)

From these equations we derive the following practical rules:

274. RULE for bridges that are gravelled. Multiply the width of the bridge by the quare of half the span, both in feet; and divide this product by the rise in feet, mul-

tiplied by the number of ribs; the quotient multiplied by the decimal 0·0011, will give the area of each rib in feet.

275. RULE for bridges where the roadway is only planked. This rule is the same, except multiplying by the decimal 0·0007 instead of 0·0011.

*Example.* Let it be required to determine the area of the ribs for a bridge of 200 feet span, to rise 15 feet, and be 30 feet wide, with 3 curved ribs. Then the half of the span is 100 and its square is 10000; and $\frac{30\times 10000}{3\times 15}\times 0{\cdot}0011=\frac{300000}{45}\times 0{\cdot}0011=7{\cdot}333$ feet nearly, for the area of each rib. Such a rib may be formed by making it three pieces in depth and two in thickness, similar to those of the bridge near Bamberg, *Plate* XVI. *fig.* 96; or to the design, *fig.* 112, *Plate* XIX.

276. Having now given an easy rule for determining the area of the rib, so that it may resist the greatest pressure that can occur from an uniform load, we must next inquire whether the strength so determined will be sufficient to resist the greatest load that can be applied at one point.

The bridge is supposed to be in a state of equilibrium when acted on by its constant load only; and the greatest strain that can arise from a load collected at one point will take place when that load is applied at one-third of the span from the abutment. But a load so applied must strain the bridge at three points, as has been already stated (art. 128;) and the greatest load likely to be upon one point at one time, will never exceed 50,000 pounds, and in narrow bridges it should not be considered more than 20,000 pounds.

277. Let the load be considered to act at F, *fig.* 108, *Plate* XVIII. then the strained points will be at F, G, and H. If the effect of the connection at F be omitted, the scantling that would sustain any given load at one point may be determined by art. 128, Sect. II. where an example is given. The other parts of the bridge, such as the joists and other horizontal timbers, will be easily determined by the rules already given, when the weight to be supported by them is known, and which will of course always be given by the nature of the construction.

In large bridges the depth of rib necessary to secure stability will always be greater than that which would be sufficient to resist the pressure of the uniform load; for by referring to art. 128, Sect. II. it will be found that the area of each rib should be 8·83 feet, when there are 3 ribs for a 200 feet span; but we have seen, in art. 275, that an area of 7·333 feet is sufficient to resist the pressure of the uniform load.

If the amounts of the loads upon a bridge be varied from those I have assumed, it will be easy to change them in the rules according to the particular circumstances of the case; I scarcely need add, that the loads should be the greatest probable.

# SECTION IX.

## OF JOINTS AND STRAPS.

278. THE joints having to support whatever strains the pieces joined are exposed to, should be formed in such a manner that the bearing parts may have the greatest possible quantity of surface; provided that surface be made of the best form for resisting the strains.

For, should that part of the joint which receives the strain be narrow and thin, it will of course either indent itself into the pieces to which it is joined, or become crippled by the strain; and, whichever of these happens, a change must be produced in the form of the framing.

The effect of the shrinkage and expansion of timber should also be considered in the construction of joints. On account of the shrinkage of timber dovetail joints should never be used in carpentry, as the smallest degree of shrinking allows the joint to draw out of its place; and, consequently, it loses all its effect in holding the parts in their proper situation. Dovetail joints can only be used with success when the shrinkage of the parts counteract each other; a case which seldom happens in carpentry, but is common in joinery and cabinet-making.

Joints should also be formed so that the contraction or expansion may not have a tendency to split any part of the framing. The force of contraction or expansion is capable of producing astonishing effects where the pieces are confined, and may sometimes be observed in framing that has been wedged too tightly together in improper directions. The powerful effect of expanding timber is well known to quarry-men, as they sometimes employ its force to break up large stones.

279. In forming joints the object to be attained should always be kept in view; as that which is excellent for one purpose may be the worst possible for another. This consideration then must guide me in the division of this section, which will be considered under the following heads:

First, Of lengthening pieces that are strained in the direction of their length.

Secondly, Of lengthening pieces exposed to cross strains; and building beams.

Thirdly, Of lengthening beams that have to resist compression.

Fourthly, Of joints for framing.

Fifthly, Of joints for ties and braces.

1. *Of lengthening Pieces of Timber that are to resist Strains in the Direction of their Length.*

280. The simplest and perhaps the best method of lengthening a beam is to abut the ends together, and place a piece on each side; these, when firmly bolted together, form a strong and simple connection. Such a method of lengthening a tie is shown by *fig.* 120, *Plate* XX.; and is what ship-carpenters call *fishing* a beam. It is obvious, however, that the strength in this case depends on the bolts, and the lateral adhesion and friction produced by screwing the parts tightly together.

The dependence on the bolts may be much lessened by indenting the parts together, as shown by the upper side of *fig.* 121; or by putting keys in the joint, as shown by the lower side of the same figure; but the strength of the beam will be lessened in proportion to the depth of the indents.

The only reasons for not depending wholly on bolts are, that should the parts shrink ever so little, the bolts lose a great part of their effect; and the smallness of the bolts renders them liable to press into the timber, and thus to suffer the joint to yield.

The sum of the areas of the bolts should never be less than two-tenths of the area of the section of the beam; and it is not a good practice to put bolts near to the ends of the pieces.

281. The most usual method of joining beams is that called *scarfing*, where the two pieces are joined so as to preserve the same breadth and depth throughout; and wherever neatness is preferable to strength this method should be adopted.

From *fig.* 122 to *fig.* 129 various methods of scarfing are shown. The first (*fig.* 122) is the most simple; it depends wholly on the bolts, and in this and like cases, it is best to put a continued plate of iron on each side for the heads of the bolts. The ends of the plates may be bent and let into the beams.

282. *Fig.* 123 is another very common, but not so good a combination, as the bolts do not press the surfaces in a perpendicular direction; and an oblique pressure, such as will have place in this example, must have some tendency to separate the joint, without any advantage in other respects.

283. *Fig.* 124 is a joint that would do without bolts, but it is clear that the strength would not be quite so great as half the strength of an entire piece; the key, or double wedges, at *a*, should only be driven so as to bring the parts to their proper bearing, as it would be better to omit it, than to drive it so as to produce much constant strain on the joint. It is not necessary that there should be a key, except when bolts are to be added, and then it is desirable to bring the joints to a bearing before the bolts be put in. The addition of bolts and straps makes this an excellent scarf.

284. *Fig.* 125 is a slight modification of the last described scarf, where the keys are

supposed to be of hard wood; if of a curled grain, so much the better. In this form the scarf is easier to execute, and equally as good, as the last, when bolts are used.

285. *Fig.* 126 represents a very common form, and a very good one, but it appears to me inferior to the two preceding ones (*fig.* 124 and 125;) and it is much more difficult to make a sound joint of this form.

When bolts are added, and they are always necessary in pieces exposed to considerable strains, then the scarf represented by *fig.* 127 is a very good and strong form for a scarf.

*Fig.* 128 differs from the last only in having keys instead of being tabled together.

286. *Fig.* 129 represents a scarf where the oblique joints in the last examples are avoided, and the same degree of strength is obtained; at the same time it is very simple and easy to execute.

287. To determine the length of a scarf, in joining beams, it is necessary to know the force that will cause the fibres of timber to slide upon each other. The researches that have been made on this subject have already been laid before the reader in Sect. II. art. 115 and 116. To apply them to our present object, let AB, *fig.* 130, *Plate* XXI. be part of a scarfed beam, strained in the direction of its length, and put together without bolts. Now it is plain that the strength of the part $cb$ must be exactly equal to the force that would cause the fibres to slide at the dotted line $cd$; for, if the part $cd$ were shorter, the joint would be less strong than it is possible to make it. Also, if the depth of the indent $ac$ be too small, it would be crushed by the strain; consequently, the parts must have a certain proportion, so that the joint may be equally strong in each part.

288. In the first degrees of extension and compression the resistance is equal, therefore the depth of the indent $ac$ must be equal to the part $cb$, in order that the strain may be equal; and it is evident, that when there is only one indent, as in this example, the depth $ac$ should be one-third of the whole depth. Also, let $d$ be the depth of the beam, and $m$ the number of indents; then $\frac{d}{3m}$ = the depth of each indent. Or the sum of the depths of the indents must be equal to one-third of the depth of the beam.

289. To determine the length of the part $cd$, we must know the ratio between the force to resist sliding and the direct cohesion of the material. Let that ratio be as $1 : n$; then $cd$ must be equal $n$ times $cb$; that is, in oak, ash, or elm, $cd$ must be equal to from 8 to 10 times $cb$.

In fir and other straight grained woods $cd$ must be equal to from 16 to 20 times $cb$.

290. Hence may be derived some maxims that will be sufficiently accurate for practical purposes:

1. In oak, ash, or elm, the whole length of the scarf should be six times the depth or thickness of the beam, when there are no bolts.

2. In fir the whole length of the scarf should be about twelve times the thickness of the beam, when there are no bolts.

3. In oak, ash, or elm, the whole length of a scarf depending on bolts only, should be about three times the breadth of the beam; and for fir beams it should be six times the breadth.

4. When both bolts and indents are combined, the whole length of the scarf for oak and hard woods may be twice the depth; and for fir, or soft woods, four times the depth.

### II. *Of lengthening Beams that are intended to resist Cross Strains, and Building Beams.*

291. Beams to resist cross strains require to be lengthened more frequently than any others, and, from the nature of the strain, a different form must be adopted for the scarf from that which is best for a strain in the direction of the length. There are cases where beams are exposed to both strains at the same time, but the cross strain is generally that of the most importance. Of this we have an example in the tie beam of a roof, where the strain in the direction of the length is very small compared with the cross strain.

Let CD, *fig*. 131, *Plate* XXI. represent a beam strained by a load at E, and supported at the ends. All the parts above the middle of the depth, *bc*, will be compressed, all below will be extended; therefore, the square abutment *ae* is better for the upper side than any complicated joint whatever; and it is evident, that all oblique joints should be avoided on the compressed side. In this figure the whole of the strength of the lower side depends on the bolts and strap.

292. *Fig*. 132 shows another form, where the lower or extended side is indented so as not to depend wholly on the strap and bolts; and a key is introduced to tighten the scarf. It will readily appear, that had the joint been cut to the dotted line instead of the oblique line, the strength would have been much impaired.

*Fig*. 133 is another form with some slight alterations.

293. *Fig*. 134 represents an angular view of a scarf where it is jointed the contrary way. An iron plate at *abcd* is supposed to be removed, which shows the tongue at *e*. This method appears to me to employ more of the strength of the timber than any other, and is very well adapted for a tie beam where it is strained both across and in the direction of its length.

In all these cases the depth of the indents, and the length of the scarf, will be obtained by the same rules as for beams strained in the direction of their length. See art. 288 to 290.

In scarfing beams to bear a cross strain it would be a great advantage to apply hoops

or straps instead of bolts, as the coachmakers and ship-carpenters do. It would be easy to form the scarf so that hoops might be driven on perfectly tight.

There is no part of carpentry that requires greater correctness in workmanship than scarfing; as all the indents should bear equally, otherwise the greater part of the strength will be lost. Hence we see how very unfit some of the complicated forms shown in the old works on carpentry were for the purpose. It is certainly very absurd to render the parts difficult to be fitted when the whole of the strength depends on their fitting well. "But many," says Professor Robison, "seem to aim at making the beam stronger than if it were of one piece; and this inconsiderate project has given rise to many whimsical modes of tabling and scarfing*."

### *Building Beams.*

294. The manner of building beams has already been considered in Sect. III. art. 143 to 146. It may not be superfluous here to remark, that the position of the indents is not a matter of indifference. If two plain pieces were laid upon one another, and supported at the ends, the pressure of a weight applied in the middle would cause them to bend, and the touching surfaces would slide against one another. The upper piece sliding towards each end upon the lower one. This sliding is effectually prevented by indenting the surfaces, as is shown in *fig.* 135, *Plate* XXI. when the pieces are bolted together; but if the same indents be reversed, as in *fig.* 136, they produce scarcely any effect, and nearly the whole strain is upon the bolts.

Wherever the principal strain on the beam may happen to be, to that point, as at C, *fig.* 135, the indents should direct their square abutments; that is, towards the straining force. When the beam is uniformly loaded, the greatest strain is at the middle.

I have often seen, in drawings, all the indents put the same way, and sometimes as in *fig.* 136; otherwise the preceding remarks would have appeared to have been unnecessary.

If the depth of the indents be too small in a built beam, they will not be capable of resisting the pressure; and if they be made too deep, the number of fibres will be diminished, and consequently the strength of the beam; therefore there is a depth for the indents, by which a maximum of strength will be gained. Duhamel undertook to ascertain the proper depth by experiments†; and the general rule I have given in art. 145, Sect. III. agrees extremely near with the case he tried.

* Art. Carpentry, Supplement to the Encyclopædia Britannica.

† Transport des Bois, p. 498.

III. *Of lengthening Beams that are intended to resist compressing Forces.*

295. When a post or strut is required to be longer than timber can be procured, as sometimes may occur in the construction of wooden towers, spires, wooden bridges, or centres, the same form of joint or scarf is applicable as when the piece is pulled in the direction of its length, with this difference, that there must not be any inclined or oblique parts in the scarf.

*Fig*. 122, 124, 125, 129, 130, and 134, of *Plate* XX. and XXI. will answer equally well for posts or ties, only it would be better to tongue the ends as at *e*, *fig*. 134.

In *fig*. 120 a piece on each of the four sides would be necessary, without some other mode of strengthening it should form a part of the framing to which it is to be applied. It is not a very neat method of piercing a strut, but it is one that is very convenient, especially in temporary structures, such as centres, where it may generally be braced in one direction, and where a more laboured form of joining would be much out of place.

IV. *Of Joints for Framing.*

296. *Of Joints for bearing purposes.*—The joint of a binding joist into a girder is an example of this kind of joint. The greatest strains upon the fibres of a girder are at the upper and lower surfaces, and the strain gradually decreases towards the middle of the depth, where it becomes insensible; hence the most suitable place for a mortise is at the middle of the depth.

The upper side being compressed, it is imagined by some writers that the tenon might be made to fill so tightly that the strength of the girder would not be impaired by it, but this is a mistake; for any one who knows any thing of the practice of carpentry, knows that it cannot be done in an effectual manner: besides, the shrinkage of the joist would soon render it loose, however tightly it might be fitted in the first instance.

Considering then that the best place for a mortise in a girder, or other beam in a like position, is at the middle of its depth, the next point is to consider the best place and form for the tenon.

If the tenon be near the lower side, it will evidently have the advantage of employing most of the strength of the joist; but this, on account of the strength of the girder, cannot be adopted; therefore, the form in general use represented in *Plate* IV. *fig*. 46, appears to combine all the advantages required. The tenon being one-sixth of the depth, and placed at one-third of the depth from the lower side.

297. Binding joists, or any other beams in a like position, should never be made

with double tenons; for, as Mr. Price has judiciously remarked, it weakens the timber framed into, and both tenons seldom bear alike; besides, in pinning it rarely happens that there is a draft on both tenons, unless the pin be as tough as wire*.

All horizontal timbers for bearing purposes should be notched upon the supports rather than framed between, wherever it can be done, as much additional strength is gained by preserving timbers in continued lengths. The same observation applies to inclined timbers, such as common rafters. See Sect. II. art. 95.

298. *Of the Joints of Framing.*—The object to be obtained by a system of framing is to reduce all the pressures into the directions of the lengths of the pieces composing the frame; therefore the form of the joint should be made so as to direct the pressures into the axes of the pieces. As when the direction of the strain does not coincide with the axis of the piece strained, the strain will be much increased. Now, from the form of the joints commonly employed, it must generally happen, that by shrinkage, or settlement, the joints will bear only upon the angular points of the joint; which not only gives a considerable leverage to the straining force, but also, by the whole bearing being upon an angle, that angular point must be either indented or crippled by the strain, which of course causes a further settlement. The extent of the evil of partial bearings becomes very manifest when the strains are considerable. In the centres of the Bridge of Neuilly seven or eight pieces in each frame were split from end to end, and many others bent considerably; and in these centres the joints were not very oblique, otherwise the effects would have been more serious. Perronet was sensible of the cause, and in order to correct it, he formed the abutments according to an arc of a circle, of which the other extremity of the piece was the centre.

This method was adopted for the joints of the centre for the Bridge of Sainte Maxence, and also in that for the Bridge de la Concorde, at Paris; and it was effectual in preventing the splitting and bending of the pieces †.

Circular abutments have been strongly recommended by Professor Robison ‡, and they certainly might be employed with much advantage. The principle is similar to the well known contrivance called the ball and socket; and to the joints of animals, where, with considerable latitude of motion, uniformity of pressure is preserved. That they require more labour, I am well aware, but were the labour doubled, it would be, comparatively, a trifling object in framing of importance; and for any other purpose it is not recommended.

It is obvious, that when the one end of the piece moves a corresponding movement will take place at the joint, and when the radius of curvature at the joint is small, as it

* British Carpenter, Introduction.

† Gauthey, Construction des Ponts, tome ii. p. 5 et 6.

‡ In the Encyclopædia Britannica, art. Carpentry, Supplement, p. 641; and Parliamentary Report on the Improvement of the Port of London.

is in the joints of animals, the motion at the joint will scarcely be perceptible. For in a roof of a 30 feet span a sinking of six inches in the middle would not cause the joints to slide more than one-tenth of an inch.

I will now proceed to notice some of the joints of most common occurrence, and point out the advantages to be obtained by altering the forms of them.

When one piece is perpendicular to another, as, for example, a post upon a sill, the most usual, as well as the most easy method, is to make the joint square, with a short tenon of about one-fourth of the thickness of the framing, to retain it in its place.

But if the joint be not very accurately cut, the whole load will bear upon the projecting parts; consequently, the centre of pressure will seldom coincide with the axis of the post, and its power to resist pressure will be much lessened. See Sect. II. art. 127.

If, instead of cutting the joint square, it were cut to form an angle, as is shown by *fig.* 137, then a very little care in cutting the joint would make the centre of pressure coincide with the axis.

299. Now whether the joint be square or angular, a slight inclination from the perpendicular will throw the pressure upon one corner; but if the joint be described from a centre situate in the axis, and with a radius not much greater than half the breadth of the post, as is shown in *fig.* 138; then, with any change of position, the joint will slide till the pressure be uniform upon the joint; and if the joint be moderately well made, the pressure will not act with any sensible leverage upon the post.

300. When the pieces to be joined are not at right angles to one another, the joints may be of two kinds; the principal rafter of a roof affords an example of each. Before proceeding to show the nature of these joints, it is necessary to state, that the direction of the strains, as well as their magnitude, as determined by the principles laid down in Sect. I. remain sensibly the same, whatever may be the form of the abutting joints, except in as far as the form of the joint alters the points of bearing; which may in some cases cause the pressure to act with a leverage nearly equal to half the depth of the beam. The strength of the joint itself depends upon its form, as it may be so made that there will be a tendency to slide, which it would be well to avoid, without having recourse to straps.

The resistance at the joint is always most effectual when the abutment is perpendicular to the strain, but where the angle formed by the inner sides of the pieces is very acute, this kind of abutment cannot be obtained, at least not without wounding the tie too much.

Let ABC, *fig.* 139, be the joint of a principal rafter upon the tie beam; where the dotted line AB shows the direction of the straining force, and B*a* is one of the abutting surfaces. Draw *ac* perpendicular to B*a*; then, by the principles of the resolution of forces (Sect. I. art. 28) *ca* will represent the force pressing on the inclined part, B*a*, of the joint; and there will remain a force represented by B*a* to be sustained by the

abutment B*d*. And, as this abutment will resist the force most effectually when it is perpendicular to it, therefore B*d* should always be perpendicular to B*a*; the same will be true in whatever direction the straining force acts.

*Fig.* 139 shows one of the most common joints; B*a* and B*d* are the abutting surfaces, which are to be perpendicular to each other; and *b e* shows the tenon, the thickness of which may be about one-fifth of that of the framing. This joint might always take better hold of the tie beam than it is generally made to do, without any risk of weakening it. In general, B*d* should somewhat exceed half the depth of the rafter, and the joint should be left a little open at *a*, in order that it may not be thrown off at B, by the settling of the roof.

301. *Fig.* 140 is a form that is approved by some writers, but by others it is considered inferior to the one already described. The dotted line shows the form of the tenon; but it would be better put together in the same manner as the joint to be described in the next article.

302. *Fig.* 141 is a very good form for a joint, as *bd* is perpendicular to the strain, considering the strain to be in the direction of the rafter, which is near enough to the truth for our present purpose. The best method of forming this joint is shown by the projected sketches A and B; as by this method it is easy to see when they are accurately fitted; whereas in a mortise and tenon joint this cannot be done, and they are often very imperfectly fitted, because it is easy to conceal any defect.

303. *Fig.* 142 shows a joint with a curved abutment; the line BA represents the direction of the strain; and *c* the centre, which should be in this line. The radius for describing the joint should be greater than half the depth of the rafter; and the part between *a* and *b* of the joint should be left open to admit of any degree of settlement that may take place. The projected sketches, C and D, show the manner of forming the joint.

Sometimes double abutments are used in joints, but it requires both great accuracy in workmanship, and also that the roof should not settle more or less than the workman allows for, in order to make both abutments bear equally; therefore I consider one good abutment preferable to two. Professor Robison very justly remarks, that "because great logs are moved with difficulty, it is very troublesome to try the joints frequently to see how the parts fit; therefore we must expect less accuracy in the interior parts. This should make us prefer those joints whose efficacy depends chiefly on the visible joint*." But to make double abutments still further increases the difficulty, without adding any thing to the security of the joint.

304. The joint at the upper end of a principal rafter differs from that at the lower end in some respects; but the difference is not material in respect to the principle of

* Encyclopædia Britannica, art. Carpentry, p. 641.

forming the joint. Making the king post larger at the head enables us to get a more effectual abutment; and this abutment should be, in common joints, square to the back of the rafter, as at A, in *fig.* 145, *Plate* XXII. with a short tenon shown by the dotted lines. When the head of the post is not sufficiently large to get the abutment square to the back of the rafter, it is usual to cut it as at B. In either case the joint should be left a little open at *a*; so that when the roof settles it may not bear upon the acute angle.

The same remarks will apply to all similar joints; such, for example, are the joints between the braces or struts and king post at C and D, *fig.* 145.

But the joints D and B would be better formed in the manner shown at A and B, *fig.* 146, where *ab* is at right angles to *bc*. The reason for this form is given in a preceding article (art. 302.) The joints may be made as shown by the projected sketches E and F.

305. A joint with a curved abutment is shown by *fig.* 147; BC represents the middle of the depth of the rafter, and *c* the centre from which the curve is described; the radius C*c* should not be less than half the depth of the beam. A and D are projected sketches of the joint.

In *fig.* 147, E shows a joint for the straining beam of a roof, and G is a projected sketch of the joint. As a further security, the piece F might be nailed upon the queen post C. The lower part of *fig.* 147 shows the joint for struts or braces.

306. Instead of the common method of framing the king or queen posts between the ends of rafters and the like, it is much better to make the rafters abut against one another, end to end; and to notch a piece on each side, and bolt through these pieces. I have called these pieces *suspending pieces,* because they serve to suspend the tie beam. (The term post is ridiculous, because it conveys a false notion of the office of the piece; but it is difficult to change a term in common use.) *Fig.* 148 and 149 show this method of joining. It has been long in use for centres, bridges, and roofs, as may be seen in the plates of the Bridge at Schaffhausen*, the Bridge of Ritter near Berne†, the roof of the Riding House at Moscow (*Plate* XI.;) and in some very good roofs lately executed in this country.

The German carpenters, and, I believe, many others, put a piece of lead between the abutting surfaces of their joints, in order to equalize the pressure. This method is not, however, so useful in timber-work as it is in stone-work; and I would, for the joints in carpentry, give the preference to putting a plate of cast iron between the abutting surfaces.

* Plans, Elevations, and Sections, of the curious Wooden Bridge at Schaffhausen. Taylor, Holborn.

† Rondelet, l'Art de Bâtir, tome iv. planche 143.

### V. *Of Joints for Ties and Braces.*

307. There is no part of carpentry where defective joints are attended with such serious inconveniences as the joints of ties, nor are there any other joints so often ill constructed. It is not easy to make a good tie joint, from the very nature of timber, and therefore many ties should not be used where it is possible to avoid them. I have before stated, "that dovetail joints should never be used in carpentry" (art. 278;) and the maxim cannot be too strongly urged, wherever the joint is intended to hold the parts together.

For let A, *fig.* 143, *Plate* XXI. represent the angle of a building, where the wall-plates are joined by a dovetail joint; the part *ab* being the crossway of the wood, will shrink in drying; and as the other piece is the lengthway, its shrinking will be insensible; therefore a very small degree of shrinkage will allow the joint to draw considerably, as is shown by the dotted lines. A joint made as shown in *fig.* 144, avoids any danger of giving way from the shrinking of the timber, and is better than any dovetail joint whatever.

Dovetail joints, or dovetail tenons, have been used in various parts of carpentry; such as the collar beams of small roofs, the lower end of king and queen posts, and for joining plates, and the like. In all these cases they are the worst kind of joints that can be used. The *carpenter's boast* must also be classed as a dovetail joint equally as defective as any*.

308. *Fig.* 150 shows a method of notching a collar beam, C, into the side of a rafter R, which is far superior to a dovetail joint.

A stout pin, of tough but straight grained oak, is an excellent addition to a tie joint, and is more economical than iron bolts. The excellence of wooden pins is fully shown by their extensive use in ship-carpentry, as they form the chief connection of ship-timbers.

### OF STRAPS.

309. "A skilful carpenter," says Professor Robison, "never employs many straps, considering them as auxiliaries foreign to his art †;" and indeed they are seldom necessary, except to suspend the tie beam to the king post, and to secure the feet of the principal rafters to the tie beam of a roof.

* The carpenter's boast is described by Mr. Nicholson, Carpenter's Guide, p. 55, 6th edition, and need not be repeated here.

† Encyclopædia Britannica, p. 642, art. Carpentry, Supplement.

*Strap for King or Queen Post.*—In *fig.* 145 *s* shows a strap for suspending the tie beam to a king or queen post; its hold of the post may be improved by turning the ends, as at *dd*, in the section E; these, when well fitted, will, with the addition of bolts, give the strap a firm hold; or staples, as in *fig.* 146, may be used for a slight roof. The strengths of straps for different bearings are stated below. When the longest unsupported part of the tie beam is

10 feet, the strap may be 1 inch wide by $\frac{3}{16}$ inch thick.
15 .................. $1\frac{1}{2}$ .......... $\frac{1}{4}$
20 .................. 2 .......... $\frac{1}{4}$

These dimensions are quite sufficient for common purposes; but where the machinery of a theatre, or other heavy loads, are to be borne by the tie beams, the straps must be made stronger in proportion to the load.

Where suspending pieces are used instead of queen posts, the same kind of strap will apply, as is shown in *fig.* 149.

310. *Strap at the Foot of principal Rafter.*—A strap at the foot of a principal rafter is intended to form an abutment for it, in case the end of the tie beam should fail. If the strap be put too upright it will, instead of forming an abutment, become quite loose when the roof settles; and as it is intended to prevent the rafter foot sliding along the tie beam, an oblique position, as shown by *fig.* 140 and 151, will be the most effectual. Straps of the same size as are used for the king post will be sufficient. In bolting on straps they ought to be drawn tight; Mr. Price recommends square bolts for this purpose; he says, "for this reason, if you use a round bolt, it must follow the auger, and cannot be helped; but by helping the auger-hole, that is, by taking off the corners of the wood, you may draw a strap exceedingly close, and at the same time it embraces the grain of the wood in a much firmer manner than a round pin*."

Sometimes a bolt is used put through square from the back of the rafter, with cross plates at the head and nut. *Fig.* 139 shows this method, the dotted lines representing the bolt.

311. It must be remembered, that thin plates of iron decay very rapidly, particularly in damp situations; therefore they should be well secured against rust by being painted as soon as they are made. Mr. Smeaton, writing on this subject, says, "I had observed, that when iron once gets rust, so far as to form a scale, whatever coat of paint or varnish is put over this, the rust will go on progressively under the paint." The

* British Carpenter, p. 18.

method he used to prevent iron rusting was to heat the whole of the iron-work to about a blue heat, and immediately strike it over the surface with raw linseed oil; the next day, if properly done, it appears as if a coat of varnish had been laid on*. By this method the pores of the iron become filled, and effectually protected from corrosion.

Another method, that is easily applied to small articles, consists in heating the metal, and rubbing it over, while hot, with wax. By this process the iron acquires an extremely uniform coating.

Nails and other small fastenings might be rendered much more lasting by boiling them in linseed oil. This is often practised by slaters to protect their nails from rust.

As it is difficult to heat large articles, a coating that can be applied in a cold state is much better. One that dries quickly, and, it is said, perfectly preserves from rust the metals upon which it is laid, is described in the Repertory of Arts†. It is prepared as follows: Grind to an impalpable powder one part (by weight) of black lead (plumbago), with which mix four parts of sulphate of lead, and one part of sulphate of zinc: to this mixture add, by degrees, sixteen parts of boiled linseed oil.

As strapping is often applied to prevent accidents, and to connect the parts when the timber itself is likely to decay, it is obvious that the iron-work should be rendered as durable as possible, and particularly where it is exposed to the weather. I lay the more stress upon this point, because it is one often neglected, and is of importance.

* Historical Account of the Construction of Edystone Light-house, p. 182.

† Repertory of Arts, &c. second series, vol. xxvii. p. 314.

# SECTION X.

## ON THE NATURE AND PROPERTIES OF TIMBER.

312. WOOD is that substance which forms the principal part of the roots, trunks, and branches, of trees and shrubs; and its usefulness in building and the mechanical arts is well known.

The *woods* of different trees differ much in strength, hardness, durability, and beauty; and, consequently, in their fitness for the various purposes to which they are applied. The wood which is felled and seasoned for the purpose of building is called *timber;* and in stating the properties of woods, I shall consider those only which are fit for timber.

313. If the stem, or trunk, of a tree be cut across, the wood is found to be made up of numerous concentric layers or rings; very distinct in some trees, but less so in others. One of these layers is formed every year; consequently their number corresponds nearly with the age of the tree. Each layer consists, in general, of two parts; the one solid, hard, heavy, and dark coloured; the other of a lighter colour, porous, and soft; which renders the lines of separation between the annual layers distinct. Scarcely any two layers of the same tree are precisely alike, either in the proportion of the hard part, or in the thickness of the layers; as the layers vary in thickness according to the degree of vegetation which took place in the years of their formation: and also in the same tree they vary in thickness, either according to the situation of the principal roots, or the aspect; the annual layers being always thicker on that side of the tree which has been most favourable to the growth of the roots, or that has had the advantage of a good aspect.

314. The structure of wood, and the nature of the vessels through which the fluids move in the living plant, are not thoroughly understood: indeed the study of vegetable anatomy is attended with considerable difficulties; but some important facts have been ascertained that contribute materially towards a more perfect knowledge of the nature and properties of wood.

Wood appears to be composed of various vessels, which, in the living tree, convey the fluids necessary to its growth; between those vessels there are cells interposed. There is nothing of the character of solid fibres in wood, except the thin membraneous coats of the cells and vessels, which adhere so slightly together in recently formed wood, that it is easy to separate them. The vessels in the growing tree are intended to convey a watery fluid, called the sap, from the roots to the leaves; when it arrives at

the leaves it undergoes some changes, and returns through the bark*; and the bark being expanded by this accession of moisture, rises from the wood, and leaves a cavity that becomes filled with the returning sap, which gradually hardens and forms a new layer of wood. The rising sap flows chiefly through the annual ring next the bark; and from the experiments of Mr. Knight† it appears, that the sap during its ascent dissolves some portion of a substance that had been deposited in the vessels of the wood during the preceding winter, for the nourishment of the buds, leaves, and young wood; hence the flowing sap is more dense in the upper than in the lower part of a tree. Dr. Darwin draws a like conclusion from the debarked oaks producing leaves‡.

In trees, as the leaves expand the sap ceases to flow, and the bark again adheres to the wood; and from the middle of June to the middle of August, there appears to be a pause in vegetation; but after this period the sap again begins to flow, and the bark which adhered so closely in the preceding months may be separated as easily as in the spring.

315. The sap which rises through the wood, from the roots, is very different in its nature from that which descends through the bark to form the new layer of wood. That which ascends is nearly as liquid as water, and is called the *common sap*. It has in general a sweetish taste, and contains sugar and mucilage. It always contains an acid, sometimes in a free state, sometimes combined with lime or potash. When this sap is left to itself, it soon ferments and becomes sour; and when the proportion of sugar is considerable, it will undergo the vinous fermentation§.

The descending sap, called the *proper sap*, differs so considerably in different trees, and is so difficult to procure in a separate state, that its properties have not been much examined. It is always less liquid, and contains a much greater proportion of vegetable matter than the common sap. It is also very probable that trees of the same kind produce proper sap of different qualities in different climates, as we find the facts established respecting timber the growth of one climate are not applicable to the same species of timber grown in another climate.

316. That part of the wood next the bark is called *sap-wood*, because it is through it chiefly that the sap ascends; and as it is shown by Mr. Knight to contain the vegetable matter to be expended in forming leaves and buds, it is reasonable to suppose that the sap-wood must be more prone to decay than the internal part of the tree, called the heart-wood.

As trees increase in size the oldest part of the sap-wood gradually loses all vegetable

* Art. Anatomy, Vegetable, Supplement to the Encyclopædia Britannica, p. 292.

† Philosophical Transactions, 1805.

‡ Phytologia, p. 159.

§ The properties of the different kinds of sap that have been examined are given in Dr. Thomson's System of Chemistry, iv. 209—213.

life, and the more fluid parts of it are either absorbed by the new forming sap-wood, or evaporated; its vessels and cells become closed by the pressure of the new forming wood, and it ceases to perform any other part in the growth of a tree than to support it. When these changes have taken place it is found to be more compact, and generally of a darker colour; and also contains only a small proportion of vegetable matter besides that kind which is called the *woody fibre* by chemists. It is then heart-wood, or wood in its most perfect state.

The sap-wood is softer, and generally lighter coloured than the heart-wood, and contains a considerable portion of vegetable matter, that partakes of the nature of the sap which ascends through it. It is found to decay rapidly, and is also very subject to worms. The reason is obvious, for it contains the food which they live upon, and which is absorbed or evaporated from the heart-wood.

The proportion of sap-wood in different trees varies very much: Spanish chesnut has a very small proportion of sap-wood, oak has more, and fir a still larger proportion than oak; but the proportions vary according to the situation and soil. Three specimens of a medium quality gave the following:

Chesnut, whole age 58 years, 15¼ inches diameter, 7 years sap-wood, ¾ inch thick.
Oak, whole age ... 65 ..... 17 .............. 17 ............. 1¼
Scotch fir ............... 24 ............................ 2¼

Therefore, if the diameter be unity, or 1, that part of it which is sap-wood will be, in the chesnut, 0·1; in the oak, 0·294; and in the Scotch fir, 0·416. The Scotch fir was the produce of the Mar Forest*.

317. The life of trees, like that of men, has been commonly divided into three stages; infancy, maturity, and old age. In the first, the tree increases from day to day; in the second, it maintains itself without sensible gain or loss; but, in the third, it declines. These stages vary in every species according to the soil, the aspect, the climate, or the nature of the individual plant.

Sir H. Davy states†, that oak and chesnut trees decay sooner in a moist soil than in a dry and sandy one; and their timber is less firm. The sap-vessels being expanded with moisture without the necessary degree of nourishing matter, the general texture becomes necessarily less firm. Such wood splits easily, and is very liable to shrink and swell with the changes of the weather.

Trees of the same kind arrive at the greatest age in that climate which is best adapted to their nature. The common oak, the fir, and the birch, thrive best towards the north; the ash and the olive tree thrive best towards the southern parts of Europe.

* These measures were taken from specimens in the collection of William Atkinson, Esq. architect to the Ordnance, &c.

† Agricultural Chemistry, p. 255, 8vo. edit.

We find, says Mirbel, the ashes of Calabria and Sicily to be longer lived than those of Prussia or Great Britain *. Oak and chesnut trees, under favourable circumstances, sometimes attain an age of about 1000 years; beech, ash, and sycamore, seldom arrive at half that age.

The decline of trees appears to be caused by the decay of the heart-wood; and it is this, as Sir H. Davy remarks †, that seems to constitute the great limit to the age and size of trees.

In trees that have not arrived at maturity, the hardness and solidity of the wood are greatest at the heart, and decrease towards the sap-wood; but in the mature or perfect tree the heart-wood is nearly uniform; while that of a tree on the decline is softer at the centre than it is next the sap-wood. These observations were made by Buffon in the course of his numerous experiments, and also by Duhamel.

### *Of Felling Timber.*

318. "It should be," says the venerable Evelyn, "in the vigour and perfection of trees that a felling should be celebrated ‡." When a tree is felled too soon the greater part of it is sap-wood, and in a young tree even the heart-wood has not acquired its proper degree of hardness; indeed the whole tree must partake so much of the nature of sap-wood, that it cannot be expected to be durable. And when a tree is not felled till it be on the decline, the wood is brittle and devoid of elasticity, tainted, discoloured, and soon decays. But in trees that have arrived at a mature age, the proportion of sap-wood is small, and the heart-wood is nearly uniform, and is hard, compact, and durable. Hence it is important that Evelyn's precept should be carefully attended to. It is true the proper age for each species has not been satisfactorily determined, but it is a point where great accuracy is not necessary; for half a dozen years in the age of a tree will not make much difference, provided it be not cut too soon. It is against cutting trees before they have arrived at maturity that I most protest; and as it is most likely to happen from interested motives, it is the more necessary to caution the carpenter in this respect. Trees increase slowly in size after they arrive at a certain age, therefore it is the interest of the timber grower to fell them before they arrive at maturity; because it is his object to obtain the greatest possible quantity of timber, without regard to the quality. But when the carpenter is sensible of the inferior quality of young timber in respect to duration, it is his province to check this growing evil, by giving a better price for timber that has acquired its proper degree of density and hardness.

* Journal of Science, &c. vol. iv. p. 11.

† Agricultural Chemistry, p. 220, 4to. edit.

‡ Silva, or a Discourse on Forest Trees, vol. ii. p. 205.

The period generally allowed for an oak tree to arrive at maturity is 100 years, and the average quantity of timber produced by a tree of that age is about $1\frac{1}{2}$ loads, or 75 cubic feet. In some instances oak trees arrive at maturity in a less time than 100 years, and in others not till after that period*.

The age of an oak tree, according to Daviller, should never exceed 200 years, nor should it be felled at a less age than 60†. Belidor states about 100 to be the best age for the oak‡. It is much to be regretted, that in districts where the oak flourishes it is seldom suffered to attain a mature age; being often cut before the trees will produce 50 feet of timber each§.

The ash, larch, and elm, should be cut when the trees are between 50 and 100 years old; and between 30 and 50 is a proper age for poplars.

The Norway spruce and Scotch pine are generally cut when between 70 and 100 years old in Norway.

319. In order that timber may be durable it is also necessary to attend to the proper season of the year for felling. But on this point there is much difference in opinion, and it is only to be decided by attending to the state of trees at different seasons of the year. The most proper period for felling timber is undoubtedly that in which it is most free from extraneous vegetable matter; or such matter as is intended to be expended in leaves and buds, and which is of a more saccharine and fermentible nature than the proper juices, or such as form the wood. A tree deposits in the sap-wood, and also in that part of the heart-wood which adjoins it, a portion of matter to be dissolved by the rising sap‖, and at the period when the leaves are putting forth, the wood must be filled with matter in a state ready for germination; consequently the timber cut at that period must be easily acted upon by heat and moisture, and subject to rapid decay; or to be destroyed by worms. Now there are two periods in the year, the spring and autumn, when trees are in a state of vegetation; therefore, at these times it is desirable to avoid felling timber for any other than temporary purposes. Of these periods the spring must be the worst, because then trees contain the greatest quantity of matter in a state fit for germination.

On the other hand, the best time for felling timber is in mid-winter, or mid-summer; as at these times the vegetative powers are at rest, or have expended all the most changeable parts in producing leaves, &c. In some kinds of trees a little after mid-summer appears to be decidedly the best time for felling. Alder felled at that time is found to be much more durable; and Ellis says, that beech, when cut in the middle of summer, is better and less liable to worm-eat; particularly if a gash be cut to let out

* First Report of the Commissioners of Woods and Forests, p. 24 and 25, 1812.

† Cours d'Architecture.

‡ Science des Ingénieurs, liv. iv chap. 1.

§ See Marshall's Southern Counties, vol. ii. p. 127.

‖ Philosophical Transactions, 1805.

the sap some time before felling*. And as summer felling is an advantage in some species, it seems reasonable to conclude that it will be so in all.

320. But in oak trees the bark is too valuable to be lost; and as the best period for the timber is the worst for the bark, an ingenious method has been long partially practised, which not only secures the bark at the best season, but also materially improves the timber. This method consists in taking the bark off the standing tree early in the spring, and not felling it till after the new foliage has put forth and died. For by the production of new buds the fermentible matter is expended, and the sap-wood becomes nearly as hard and durable as the heart-wood, being both less liable to decay, and to be destroyed by worms.

Buffon has ascertained, by experiment, that the wood is materially improved by this method of barking the trees standing in the spring, and felling them about the end of October†. Duhamel, whose extensive knowledge of the nature and qualities of woods is well known, recommends the same method; and Evelyn states, that "to make excellent boards and planks, it is the advice of some, you should bark your trees in a fit season, and so let them stand naked a full year before the felling‡. But a tree will not be benefited by standing so long; and the best time for felling appears to be when the new foliage has put forth and died, as Mr. S. Pepys observes in his paper on the subject§. I am happy to be able to add, that Mr. T. A. Knight, to whom we are indebted for many interesting as well as important facts respecting timber, has made some experiments and observations, from which he concludes, that in all cases where it is essential to give durability to the sap-wood of oak, the trees should be barked in the spring, and felled in the ensuing winter‖.

When the bark of a tree is not of sufficient value to defray the expense of stripping, the timber should be felled during the months of December, January, and February, in the winter; or during the month of July in the summer. Winter felling is recommended by most writers. According to Vitruvius, the proper time for felling is between October and February; and he directs that the trees should be cut to the pith, and then suffered to remain till the sap be drained out. The effusion of the sap prevents the decay of the timber, and when it is all drained out, and the wood becomes dry, the trees are to be cut down; when the wood will be excellent for use ¶.

A similar effect might be produced by placing the timber on its end as soon as it is felled, and it would no doubt compensate for the extra expense by its durability in use.

* Ellis's Timber Tree Improved, p. 35.

† Moyen facile d'augmenter la Solidité, la Force, et la Durée du Bois; Memoires de l'Academie des Sciences, Paris, 1738, p. 169—184.

‡ Silva, Dr. Hunter's edition, vol. ii. p. 214.

§ Philosophical Transactions, vol. xvii. p. 455.

‖ Annals of Philosophy, vol. xiv. p. 52.

¶ Vitruvius, book ii. chap. ix.

In France, so long ago as 1669, a royal ordinance limited the felling of naval timber from the 1st of October to the 15th of April. Buonaparte directed that the time for felling naval timber should be abridged to from the 1st of November to the 15th of March, in order to render it more durable*.

### *Of Seasoning Timber.*

321. When timber is felled, the sooner it is removed from the forest the better: it should be removed to a dry situation, and placed so that the air may circulate freely round each piece, but it should not be exposed to the sun and wind. Squared timber does not rift or split so much as that which is round; and where the size of the trees will allow of it, it is better to quarter them. When beams are to be used the full size of the tree, it would be a good preservative against splitting to bore them through from end to end, as is done in a water pipe. It is irregular drying that causes timber to split, and this method would assist in drying the internal part of the beam, without losing much of its strength; at the same time it would lighten it considerably.

Duhamel has shown that it is a great advantage to set the timber upright, with the lower end raised a little from the ground†; but as this cannot always be done, the timber yards should be well drained, and kept as dry as possible. Paved yards are to be preferred, and the paving should have a considerable fall, to prevent water standing. If the paving were laid with ashes it would be better; those from a forge or foundry would be excellent: even an unpaved yard would be improved by a coat of ashes, to prevent any thing growing among the timber.

If timber can be kept some time in a dry situation before it be cut into scantlings, it is less subject to warp and twist in drying; but during the time it is kept in the tree or log it should be carefully piled, so as to leave space for a free circulation of air between each piece, and also between the timbers and paving or ground. Lately, in some of the government yards, the timber has been laid upon cast-iron bearers, instead of being laid upon refuse pieces of wood; as the refuse wood is often half rotten, and must in some degree contribute to infect the sound timber. Timber is too often suffered to lie half buried in the ground, or grown over with weeds, till it be covered with fungus, and impregnated with the seeds of decay before it be brought into use.

When it shall have become convenient to convert the timber into smaller scantlings, it still requires attention; as the better it is seasoned, when brought into work, the better the work will stand, as well as be more durable. The experiments of Duhamel show that such scantlings will dry soonest in an upright position, and that the

* Encyclopædia Britannica, Supplement, art. Dry Rot.

† Transport des Bois, p. 238.

upper end dries more rapidly than the lower one*. But whether the pieces of timber be piled on the end, or laid horizontally, a free space should be left round each piece, and the situation should be dry and airy; yet not exposed to the direct rays of the sun. If the scantlings be laid horizontally, short blocks should be put between them; which will preserve them from becoming mouldy, and will contribute much towards rendering the sappy parts more durable.

Gradual drying, where the time can be allowed for it, is the most certain means of giving durability to timber, by fixing those parts of it which are most liable to be acted upon by heat and moisture.

It is well known to chemists that slow drying will render many bodies less easy to dissolve, while rapid drying, on the contrary, renders the same bodies more soluble; besides, all wood in drying loses a portion of its carbon, and the more in proportion as the temperature is higher. There is, in wood that has been properly seasoned, a toughness and elasticity which is not to be found in rapidly dried wood. This is an evident proof that some essential parts are dissipated in a high heat. Also, a forced seasoning produces a hard crust on the surface, which will scarcely permit the moisture to evaporate from the internal part, and is very injurious to the wood.

For the general purposes of carpentry, timber should not be used in less than two years after it is felled; and this is the least time that ought to be allowed for seasoning. For joiners' work it requires four years, unless other methods be used; but for carpentry natural seasoning should have the preference.

Duhamel says, that the quantity of matter which ought to be evaporated from green oak is about one-third or two-fifths of its weight; the proportion, however, will vary according to the age and quality of the timber, and the nature of the soil that produced it†. I shall attempt to establish the relation between the size of the pieces, and the time necessary to season them, in a succeeding article (see art. 327;) as it is a subject that has not received that share of attention which its importance merits.

### *Water Seasoning.*

322. On account of the time that it requires to season timber in the natural way, various methods have been tried to effect the same purpose in a shorter time. Perhaps the best of these is to immerse the timber in water as soon as it is cut down; and after it has remained about a fortnight in water, but not more, to take it out, and dry it in an airy situation.

Evelyn directs, to "lay your boards a fortnight in water (if running the better, as at

* Transport des Bois, p. 83.

† Idem, p. 72.

a mill-pond head) and then setting them upright in the sun and wind, so as it may pass freely through them, turn them daily; and, thus treated, even newly-sawn boards will floor far better than those of a many years dry seasoning, as they call it*:" and he adds, "I the oftener insist on this water seasoning, not only as a remedy against the worm, but for its efficacy against warping and distortions of timber, whether used within or exposed to the air."

Duhamel, who made many experiments on this important subject, states, that timber for the joiner's use is best put in water for some time, and afterwards dried; as it renders the timber less liable to warp and crack in drying; but, he adds, "where strength is required it ought not to be put in water†." And he found, from numerous experiments, that timber which had remained some time in fresh water lost more of its weight in drying than that which was dried under cover; and he observed, that green timber that had been steeped in water for some time was always covered with a gelatinous substance‡.

Timber that has been cut when the tree was full of sap, and particularly when that sap is of a saccharine nature, must be materially benefited by steeping in water; because it will undoubtedly remove the greater part of the fermentible matter. Duhamel has ascertained that the sap-wood of oak is materially improved by it, being much less subject to worm-eat; and also, that the tender woods, such as alder and the like, are less subject to the worm when water seasoned§. Beech is said to be much benefited by immersion; and green elm, says Evelyn, if plunged four or five days in water (especially salt water) obtains an admirable seasoning‖.

When timber is put in water it must be sunk so as to be completely under water, as nothing is more destructive than partial immersion. Salt water is considered best for ship-timber, but for timber to be employed in the construction of dwelling-houses fresh water is better.

### *Of Steaming and Boiling Timber.*

**323.** Though steaming or boiling impairs the strength and elasticity of timber, it gives another property, which for some purposes is still more desirable than strength; for boiled or steamed timber shrinks less and stands better than that which is naturally seasoned. Therefore it may often be useful to season timber in this manner where joiners' work is to be executed in oak of British growth, as without this precaution it requires a long time to season it so as to be fit for such purposes.

* Silva, vol. ii. p. 217.

† Transport des Bois, p. 247.

‡ Transport des Bois, p. 164, 168, and 171.

§ Idem, p. 172 et 176.

‖ Silva, vol. ii. p. 217.

The timber should not remain long in boiling water or steam; four hours will, in general, be quite sufficient: and after boiling or steaming the drying goes on very rapidly, but it is well not to hasten the drying too much. Steamed wood dries sooner than that which is boiled, according to Mr. Hookey's experiments*.

How far steaming or boiling affects the durability of timber has not been satisfactorily ascertained; but it is said that the planks of a ship, near the bows, which are bent by steaming, have never been observed to be affected with the dry rot†. The changes produced by boiling, as observed by Duhamel, are not very favourable to the opinion that it adds to the durability of timber. For when a piece of dry wood was immersed in boiling water, and afterwards dried in a stove, it not only lost the water it had imbibed, but also a part of its substance; and when the experiment was repeated with the same piece of wood, it lost more of its substance the second time than it did the first. The same thing takes place in green wood; and tender woods, or those of a middling quality, are more altered by these operations than hard woods, or those of a good quality‡. Dr. Watson found steeping long in cold water produced similar effects; and that box, oak, and ash, lost more weight by this process than mahogany, walnut, or deal§.

### *Of Smoke-drying, Scorching, and Charring Timber.*

324. It is an old, and a well founded observation, that smoke-drying contributes much to the hardness and durability of wood. Virgil seems to have been aware of its utility when he wrote the passage which is thus translated by Dryden:

> "Of beech the plough-tail, and the bending yoke,
> Or softer linden *harden'd in the smoke*||." Georgics, I. 225.

But this method can only be effectually applied on a very small scale; yet sometimes, for particular purposes, it may be useful to season in the smoke. As a substitute for the smoke of an open chimney, Ellis advises to burn fern, furze, straw, or shavings under the timber¶, which would destroy any seeds of fungi or worms, and so embitter

* Barlow's Essay on the Strength of Timber, p. 14.

† Ency. Brit. Supp. art. Dry Rot, p. 682.

‡ Transport des Bois, p. 138 et 144.

§ Chemical Essays, vol. iii. p. 24.

|| Beckman (in his History of Inventions, vol. ii. p. 77) quotes a passage from Hesiod to the same effect; and adds, "as the houses of the ancients were so smoky, it may be easily comprehended how, by means of smoke, they could dry and harden pieces of timber." In this manner were prepared the pieces of wood destined for ploughs, waggons, and the rudders of vessels:

> "These long suspend, where *smoke* their strength explores,
> And seasons into use, and binds their pores." Sotheby's Virgil.

¶ Timber Tree Improved, by Mr. Ellis.

the external surface as to prevent any future ill effect from either. It would be easy to contrive the means of smoke-drying for the use of a manufactory where much seasoned wood was used.

Scorching must do timber much harm when it is done hastily, so as to cause rents and cracks in it; as these become receptacles for moisture, and consequently must be the cause of rapid decay.

It must be always remembered, that charring the surface is only useful in as far as it destroys and prevents infection; and that it should be applied only to timber already seasoned; for when it is applied to green timber, it only closes up the pores at the surface, so that the internal sap and moisture cannot evaporate.

In that kind of decay which arises from the constant evaporation of moisture, charring the surface produces no effect. Duhamel made some experiments on this point, and found that there was very little difference between the posts he had charred, and those he had not charred, at the end of six years*; but as a preventive of infection by the dry rot, and of the worm in timber, charring appears to be very beneficial, and will no doubt be assisted by impregnating the timber with the bitter particles of smoke.

### *Tables of the Weight of Timber in different States.*

325. As a suitable introduction to some remarks on seasoning, I subjoin the following tables.

*Weight of a Cubic Foot of Timber, Green, and also its Weight a Year afterwards.*

From Duhamel's experiments †; reduced to English weights and measures.

| Kind of wood. | Weight of a cubic foot green. | Weight of a cubic foot one year afterwards. |
|---|---|---|
| Oak of Provence ...... | 78·25 | 68·3 |
| Elm, ditto ........... | 57·14 | 47·5 |
| Poplar, ditto ......... | 49·68 | 30·69 |
| Walnut, ditto ........ | 54·43 | 44·08 |
| Lime, ditto .......... | 45·2 | 27·96 |
| Beech of Bourgogne .. | 56·25 | 43·95 |
| White pine of Provence | 53·73 | 43·93 |
| Norway pine, dry .... | | 36·75 |

The writer of an article on Timber, in the Encyclopedie Methodique, states that the weight of a cubic foot of green oak varies from 62·5 to 66 pounds; of a cubic foot of

* Transport des Bois, p. 225, et suiv.

† Idem, p. 66.

seasoned oak, from 53·5 to 58 pounds; and a cubic foot of very dry oak, from 44·6 to 47·3 pounds*. The timber of very old trees is often much lighter than this; I have tried specimens from old trees that did not exceed 38·5 pounds per cubic foot when dry. When the specific gravity is very low it may be safely concluded that it is the wood of an old tree, and that it will be brittle and deficient both in strength and toughness.

Some experiments have been made on the loss of weight in seasoning by Mr. Couch, at the Royal Dock Yard, at Plymouth, from which the following are taken†.

| Kind of wood. | Weight when felled of a cubic foot. | Weight seasoned of a cubic foot. | Shrinkage in seasoning. |
|---|---|---|---|
| | pounds. | pounds. | |
| Oak (but end) ...... | 69 | 47¼ | $\frac{1}{32}$ |
| Elm .............. | 58¼ | 36¼ | $\frac{1}{44}$ |
| | Weight of a cubic foot when first imported. | | |
| Riga masts ......... | 42 | 40 | $\frac{1}{72}$ |
| Pitch pine, American | 47 | 46¼ | $\frac{1}{30}$ |
| Yellow pine, ditto ... | 42½ | 28¾ | $\frac{1}{144}$ |
| Spruce pine, ditto ... | 33 | 32¾ | $\frac{1}{112}$ |

To these experiments the following new ones are added, which include some varieties of wood not before tried.

| Kind of wood. | Weight of a cubic foot when green. | Weight of a cubic foot dry. |
|---|---|---|
| | pounds. | pounds. |
| Oak sap-wood (quercus sessiliflora) | 67·0 | 47·07 |
| Spanish chesnut ................ | 54·68 | 37·91 |
| Larch ...................... | 42·06 | 30·99 |
| Walnut ..................... | 57·5 | 38·5 |
| Acacia (robinia pseudo-acacia) .... | 51·25 | 46·76 |

We are also indebted to Mr. Wiebeking for some experiments on seasoning timber; and as both the kinds of timber and the times of observation are different from those already noticed, his table is a considerable addition to our knowledge of this important subject. It is, in common with all the other tables in this work, reduced to English weights and measures.

* Art. Bois, Dict. Architecture, Encyclopedie Methodique.

† Mr. Couch's Table is published in Barlow's Essay on the Strength of Timber, p. 9; and contains much valuable information.

*Weight of a Cubic Foot of Wood in different States*.*

| Kind of wood. | Weight of a cubic foot fifteen days after the wood was felled. | Weight of a cubic foot after three months' exposure to the air. | Weight of a cubic foot when dry. |
|---|---|---|---|
| | pounds. | pounds. | pounds. |
| Oak .............. | 58·74 | 56·18 | 39·27 to 39·58 |
| Larch .............. | 53·63 | 51·08 | 38·31 |
| Pine (pinus sylvestris) | 51·08 | 38·31 | 26·817 |
| Pinaster ........... | 52·35 | 33·2 | 25·54 |
| Fir (pinus picea) .... | 33·2 | 29·37 | 25·22 to 25·54 |

Wood, when it is cut into small pieces, very soon acquires its utmost degree of dryness. Dr. Watson, Bishop of Llandaff, in the month of March, cut a piece from the middle of a large ash tree that had been felled about six weeks, and weighed it; its weight was 317 grains; in seven days it lost 62 grains, or nearly one-fifth of its weight. It was weighed again in August of the same year, but had not lost any more of its weight; hence it had become perfectly dry in the short space of seven days. He also found that the sap-wood of oak lost more weight in drying than the heart-wood, in the proportion of 10 to 7†.

Mr. Pontey has ascertained that the sap-wood of larch loses two-fifths of its weight in drying ‡.

*Laws of Seasoning.*

326. The time that is required to season, or to dry a piece of timber, obviously depends upon its magnitude; for we have seen that in a small piece it will become perfectly dry in a few days: therefore some rule in this respect is desirable. A complete solution of the problem cannot be effected without more accurate experiments had been made on pieces under various circumstances. But till something better shall be done the following investigation may be useful.

The time required to dry a piece of timber will depend on the quantity of surface

* Traité contenant une Partie Essentielle de la Science de construire les Ponts, p. 114.

† Chemical Essays, vol. iii. p. 21.

‡ Forest Pruner, p. 88. Mr. Pontey is completely wrong when he supposes his experiments to furnish any rule for the time it would require to season larger pieces.

exposed to the action of the air; and while the quantity of timber remains the same, the larger the surface the sooner it will be dry.

Also, if the quantity of surface remain the same, the time of drying will be proportional to the quantity of matter; as the greater the quantity of matter under the same surface, the longer it will be in drying.

Let $l$ be the length of a tree, which may be supposed to be a cylinder, and $d$ its diameter, and $p=3{\cdot}1416$.

Then, by the principles of mensuration, the surface of the cylinder is equal to $pdl+\frac{1}{2}pd^2$; and its solid content is $\frac{1}{4}pd^2l$. But the time of drying will vary in the inverse ratio of the surface, and directly as the solid content: call this time T. Then $\dfrac{\frac{1}{4}pd^2l}{pdl+\frac{1}{2}pd^2}$ : T, or $\dfrac{dl}{l+\frac{1}{2}d}$ : T. And, if $c$ be a constant quantity, to be found from experiments, we have $\dfrac{cdl}{l+\frac{1}{2}d}=\mathrm{T}$, when the beam is cylindrical.

And in a rectangular beam $\dfrac{cbdl}{lb+ld+bd}=\mathrm{T}$; where $b$ is the breadth and $d$ the depth of the beam. When a table of reciprocals is at hand, the latter rule becomes much more convenient for calculation under the form $\dfrac{c}{\frac{1}{d}+\frac{1}{b}+\frac{1}{l}}=\mathrm{T}$.

This investigation is made on the supposition that the evaporation is free and equal at every part of the surface; but this is not the case in seasoning, as the evaporation from the ends is greater than from the sides, and greater from the upper side than from the under one; but it is perhaps sufficiently correct to be useful, at least till something better shall be done.

Equal drying would be much promoted by often turning the pieces, and by keeping them free from the ground or other damp bodies; and the more equal the drying is, the more nearly these rules will apply.

Timber is used in two states, that is, when it is *dry*, and when it is only *seasoned*. The term seasoned, however, is not very accurately defined. Rondelet considers timber to be sufficiently seasoned for carpenters' work when it has lost about one-sixth of its weight. But according to my own observations, timber has undergone what is termed a proper seasoning, when it has lost about one-fifth of its weight; therefore, I shall call that timber *seasoned*, which has lost one-fifth of the weight it had at the time of felling.

It also appears from the experiments of Duhamel* and Couch†, that timber loses about one-third of its weight in becoming dry; and such a degree of dryness being

* Transport des Bois. † Barlow's Essay on Timber, p. 13.

sufficient for the joiners' purpose, I shall consider timber *dry* when it has lost one-third of its weight.

Thus the terms *dry* and *seasoned* will have a more certain meaning; and when drying is carried to its greatest degree, the timber may be called *perfectly dry*, to distinguish it from that degree of dryness which renders it fit for joiners' work.

In order to compare the times required to season and to dry timber when the sizes of the pieces remain the same, it will be necessary to consider the progress of evaporation from the same quantity of surface.

Let the whole time be conceived to be divided into equal parts, then the quantity evaporated during any one of these parts of the time will be inversely as the square of the time between that part and the commencement. For as the time increases, the quantity of moisture decreases; and the force of evaporation being proportional to the excess of moisture, the quantity evaporated must decrease in the inverse ratio of the time; but if the evaporating force were constant, the quantity evaporated must be less and less at each successive space of time from the decrease of moisture; therefore, as both the evaporating force, and the quantity to be evaporated, decrease with the time, the quantity evaporated during any space or part of the time is inversely as the square of its distance from the commencement.

Now, according to this law, the whole quantity evaporated during any time, counting from the beginning of the process, will be inversely as the cube of that time: therefore, denoting the time necessary to season a piece of timber by unity, or 1, we may find the time required to dry the same piece. For $\frac{1}{5} : \frac{1}{3} :: \frac{1}{1^3} : \frac{1}{\text{cube of time of drying}} = \left(\frac{5}{3}\right)^3 = 4{\cdot}63$ nearly: that is, it requires 4·63 times as long to dry a piece of timber, as it does to season it, if the piece remain of the same size.

Hence it appears how slowly the process of drying goes on; and the preceding equations showing that it proceeds most rapidly in small pieces, the importance of reducing timber to its proper scantlings for use is obvious. For, however dry a piece of timber may be, when it is cut to a smaller scantling it will still shrink and lose weight, being always less dry in the centre than at the surface; and the more rapidly the drying has been carried on, the greater will be the difference. Nevertheless, in the first stages of seasoning it is best that it should proceed slowly; otherwise the external pores shrink so close as not to permit the free evaporation of the internal moisture, and the piece would split from unequal shrinking; and, lastly, it should be reduced nearly to the proper scantling some time before it be framed.

The long time which large pieces require to season should render their use less frequent, without a proper time can be allowed. In the following table I have given the times of drying and seasoning pieces of different sizes, calculated by the rules laid

down in this article, which may be useful, as it shows at once the time necessary to bring different scantlings to the same degree of dryness.

| Length in feet. | Breadth in inches. | Thickness in inches. | Time of seasoning in months. | Time of drying in months. |
|---|---|---|---|---|
| 10 | 6 | 6 | $6\frac{1}{4}$ | 29 |
| 10 | 8 | 8 | $8\frac{1}{2}$ | 39 |
| 12 | 10 | 10 | 10 | 48 |
| 12 | 12 | 12 | 12 | 57 |
| 12 | 14 | 14 | 14 | 66 |
| 12 | 16 | 16 | 17 | 76 |
| 18 | 18 | 18 | 19 | 86 |
| 20 | 20 | 20 | 21 | 96 |

## OF THE DECAY OF TIMBER.

327. Timber, when properly seasoned, is strong, tough, and elastic; but it does not long retain those properties in any state or situation. Timber is generally employed in situations where it is continually dry, where it is constantly wet, where it is alternately wet and dry, or where it is exposed to heat and continued moisture. The effect of each of these states is the next object of attention.

### *Effect of continued Dryness.*

Timber that is constantly dry, or affected only by the small quantity of moisture which it absorbs from the air in damp weather, has been known to last for seven or eight hundred years; but, even in this state, time produces a sensible alteration in its properties; for it is found to lose its elastic and coherent powers gradually, and to become brittle. Hence it is unfit to sustain the action of variable loads, though in a state of rest it may endure an immense length of time.

### *Effect of continued Wetness.*

328. The wood of trees in its natural state is a very compound substance; a certain portion of its constituents is soluble in water, another part may be extracted by alcohol, and the part remaining, after being treated with alcohol, is the pure woody fibre, or lignin, of chemists. After water has extracted all that is soluble by it from timber, it is obvious that while the timber continues immersed in water it may remain

unchanged for an indefinite period; but if it be taken out and dried, it is found to be brittle and effete; or, to use the workman's expression, "its nature is gone;" and, as Dr. Sloane has observed of oak that had been buried in a wet situation, "it dries, splits, becomes light, and soon impairs*." But though oak timber taken from bogs is always found to be brittle and in a state of decay, fir from the same bog is often, if not always, in a much sounder state.

### *Effect of alternate Dryness and Moisture.*

329. When timber is exposed to the action of alternate dryness and moisture it soon decays. It has been already noticed, that repeated steeping and drying removes a sensible portion of the wood at each operation (see art. 222 and 223;) and it is evident, that at each drying a new portion of soluble matter is formed, which either did not before exist, or which is rendered soluble by a change in its principles. This conclusion is further established by Saussure, who found that wood, the most completely freed of its soluble principles, furnishes always by maceration in water, with the contact of air, infusions holding extractive matter dissolved†. The effect of this kind of decay may be observed in weather-boarding, fencing, and in any situation where wood is constantly exposed to the vicissitudes of the weather. When the timber has been thoroughly seasoned, painting or any kind of coating that is capable of resisting moisture is the best means of preserving it from this kind of decay. (See art. 354.)

### *Effect of continued Moisture with Heat.*

330. Wood, in common with other vegetable products, when exposed to a certain degree of moisture, and at a temperature not much under 45 degrees, nor too high to evaporate suddenly all the moisture, gradually decomposes. This decomposition is called putrefaction by chemical writers, but is called the *rot* in common language. It proceeds with most rapidity in the open air, but the contact of air is not absolutely necessary. Water is in all cases essential to the process; indeed it is a principal agent in all processes of decomposition.

As the rot goes on certain gaseous matters are given out; chiefly carbonic acid gas and hydrogen gas ‡.

Pure woody fibre, alone, undergoes this change slowly, but its texture is soon broken

* Evelyn's Silva, vol. ii. p. 105.

† Dr. Murray's System of Chemistry, vol. iv. p. 321.

‡ Dr. Thomson's System of Chemistry, vol. iv. p. 396.

down, and it is easily resolved into new elements when mixed with substances more liable to change. "Any process," observes Sir H. Davy, "that tends to abstract carbonaceous matter from it must bring it nearer in composition to the soluble principles," and this is done by fermentation *. Hence it is that the sap-wood is of a more perishable nature than the heart-wood; for the sap-wood abounds more in saccharine and fermentable principles, and consequently sooner ferments. Dr. Darwin took part of the branch of an oak tree, cut in January, and divided it carefully into three parts, the bark, the alburnum or sap-wood, and the heart-wood. These were each shaved, or rasped, and separately boiled in water, and then set in a warm room to ferment. The decoction of the sap-wood passed into rapid fermentation, and became acid; but not either of the other †.

Duhamel tried some experiments to ascertain the effect of confining the sap in green timber; and found, that the pieces thus confined soon exhibited signs of rapid decay; and therefore he strongly recommends a free space for the circulation of air round the ends of joists and beams, instead of building them in the wall ‡. Duhamel also tried the effect of covering the external surface of timber with paint, tar, and pitch; and found that it contributed much to the durability of dry or well-seasoned timber, but hastened the decay of green and unseasoned timber §.

Quicklime, when assisted by moisture, has a powerful effect in hastening the decomposition of wood, in consequence of its abstracting carbon. Mild lime (carbonate of lime) has not this effect ||. But mortar requires a considerable time to bring it to the state of mild lime; therefore, bedding timber in mortar, or building it in walls where it will long remain in a damp state in contact with mortar, is very injurious, and often the cause of rapid decay. Wood in a perfectly dry state does not appear to be injured by dry lime; of this we have examples in plastering laths, which are generally found sound and good in places where they have been dry. Lime also protects wood from worms.

Volatile and fixed oils, resins, and wax, are equally as susceptible of decay as woody fibre under the same circumstances ¶; hence we see the impropriety of attempting to protect wood in any situation where the coat of paint, &c. cannot be renewed from time to time; and also, that woods abounding in resinous matter cannot be more durable than others.

Decay sometimes commences in the growing tree, for when it has stood beyond a certain age, decay at the heart has generally made some progress. (See art. 317.) I have often observed this in large girders of yellow fir, which have appeared sound on

* Agricultural Chemistry, p. 249, 4to. edit.

† Phytologia, p. 33.

‡ Transport des Bois, p. 52 et 53.

§ Idem, p. 60; also Chapman on Preservation of Timber, p. 121.

|| Agricultural Chemistry, p. 278.

¶ Idem, p. 238.

the outside, but by removing some of the binding joists have been found completely rotten at the heart*. It is on this account that the practice of sawing and bolting girders is recommended. (See art. 140, Sect. III.)

It is usual to divide the rot into two kinds, the *wet rot*, and the *dry rot;* but I have not been able to discern any real distinction between them, except that in the one the gaseous products are evaporated, and in the other the greater part of them run into a new combination, which is a species of fungus. Both, in a chemical sense, are produced by precisely the same causes, with this exception, that a free evaporation determines it to be the wet rot; a confined place, or imperfect evaporation, renders it the dry rot, as timber must be decomposed before it can become the food of a plant: they are evidently the same with the putrefaction of chemists. It is said that the decay of a post placed in the ground, or in water, is an example of the wet rot; and it is assumed, that the parts undergoing the process of decay are alternately wet and dry; but the fact is, they are constantly supplied with that degree of dampness which is essential to putrefaction. For "timber being composed longitudinally of an assemblage of pipes or tubes, it is only necessary that one end of a log of wood should be placed in a damp or wet situation, to occasion the moisture to be conveyed to the opposite end by capillary attraction†." Prevent a free change of atmospheric air, and a post so circumstanced, it is well known, would be affected with the dry rot. Hence it appears to me, that some writers are mistaken in asserting, that they are "essentially different, both in the symptoms, the progress, and the causes ‡."

When only the external part of a beam has been seasoned, and the sap has never been evaporated from the internal part, the rot will be an internal disease; and where an internal decay of this kind is found, it proves that the timber has never been properly seasoned. Mr. Bowden, in the plate to his Treatise on the Dry Rot, gives figures of such a piece; it appears to be of common occurrence; and it is evident from such examples of decay, that the want of due time and attention in seasoning is one of the chief causes of the rapid decay of ships. In Mr. Bowden's specimen the exterior part, to the depth of two inches from the outside, was as sound as any wood could possibly be; but the central part was filled with a fine, white, thread-like vegetation, extending within the above-mentioned two inches of the exterior surface, and uniting in a thick fungous coat at the end of the piece §; thus showing the depth to which the seasoning had been effected.

331. In the first stages of rotteness the timber swells and changes colour, is often covered with mucor or mouldiness, and emits a musty smell. Where the rotteness is

* I observed an instance of this kind in the repairs at Kenwood (the seat of the Earl of Mansfield) in 1815; and similar ones at some other places since that time.

† Encyclopædia Britannica, Supplement, art. Dry Rot, p. 679.

‡ Idem, p. 677.

§ Treatise on the Dry Rot, p. 11 and 15.

internal, or the timber is in a confined place, a new substance is formed between the fibres, of a spongy consistency, resembling the external coat of a mushroom; and the substance itself has been ascertained to belong to the order fungi, of the cryptogamia class of plants.

When the fungus first appears on the sides and ends of timbers, it covers the surface with a fine delicate vegetation, that has been called by shipwrights a mildew. These fine shoots afterwards collect together, and the appearance then may be compared to hoar-frost, and increases rapidly, assuming gradually a more compact form, like the external coat of a mushroom, but spreads in the form of leaves, being larger or smaller most probably in proportion to the nutriment the wood affords. The colours of the fungus are various; sometimes white, greyish white, with violet; often yellowish brown, or a deep shade of fine rich brown.

It has been considered a question of some importance to determine how fungi are propagated, or from what they originate; but as such an inquiry can be attended with little, if any advantage, in preventing the rot, it appears to be better to consider it only so far as it is a chemical change, leaving the question of their origin to the curious, as well as the distinction of the species of fungi.

In the more advanced stages the woody fibres contract lengthwise, and show many deep fissures across the fibres, similar to a piece of wood scorched by the fire. The woody fibres appear to retain their natural form, but easily crumble into a fine powder. In oak this powder is of a fine snuff-brown colour.

The fungus, when it spreads upon the surface of the wood, often becomes of a considerable size, sometimes spreading over the adjoining walls, and ascending to a considerable height.

The decayed state of a barn floor is thus described by Mr. B. Johnson: "An oak barn floor which had been laid twelve years began to shake upon the joists, and on examination was found to be quite rotten in various parts. The planks, 2½ inches in thickness, were nearly eaten through, except the outside, which was glossy, and apparently without blemish. The rotten wood was partly in the state of an impalpable powder, of a snuff colour; other parts were black, and the rest clearly fungus. No earth was near the wood*."

332. In timber of the same kind, that of the most sappy and rapidly grown trees is the most subject to decay. The wood of trees from the close forests of Germany or America is more subject to it than that of trees grown in more open situations; and it is remarked by Mr. Barrow, that "the timber brought from America in the heated hold of a ship, is invariably covered over, on being landed, with a complete coating of fungus †." Consequently, the timber must be infected with the seeds of decay before

* Transactions of the Society of Arts, &c. vol. xxi. p. 294.

† Ency. Brit. Supp. art. Dry Rot, p. 680.

it is brought into use. Also, the custom of floating timber in docks and rivers injures it very much; it would be better to sink it completely under water, as to half immerse it in water is the worst situation it can be placed in.

333. Though moisture be essential to the progress of decay, absolute wetness will prevent it, especially at a low temperature. In ships this has been particularly remarked, for that part of the hold of a ship which is constantly washed by the bilge-water is never affected by dry rot*. Neither is that side of the planking of a ship's bottom which is next the water found in a state of decay, even when the inside is quite rotten, unless the rot has penetrated quite through from the inside†.

334. Warmth and moisture are the most active causes of decay, and provided the necessary degree of moisture be present, the higher the heat the more rapid is its progress. In warm cellars, or in any close confined situations where the air is filled with vapour without a current to change it, the rot proceeds with astonishing rapidity, and the timber-work is destroyed in a very short time. The bread-rooms of ships, behind the skirtings and under the wooden floors of the basement stories of houses, particularly in kitchens, or other rooms where there are constant fires; and, in general, in every place where wood is exposed to warmth and damp air, the dry rot will soon make its appearance.

335. All kinds of stoves are sure to increase the disease if moisture be present. The effect of heat is also evident from the rapid decay of ships in hot climates‡. And the warm moisture given out by particular cargoes is also very destructive; such as cargoes of hemp §, pepper, and cotton ‖.

336. Building timber into new walls is often a cause of decay, as the lime and damp brick-work are active agents in producing putrefaction, particularly where the scrapings of roads are used instead of sand for mortar. Hence it is that bond-timbers, wall-plates, and the ends of girders, joists, and lintels, are so frequently found in a state of decay. The old builders used to bed the ends of girders and joists in loam, instead of mortar, as is directed in the act of parliament for rebuilding the city of London ¶. In this place it may not be amiss to point out the dangerous consequences of building walls so that their principal support depends on timber. The usual method of putting bond-timber in walls is to lay it next the inside; this bond often decays, and of course leaves the wall resting only upon the external course or courses of bricks; and fractures, bulges, or absolute failures are the natural consequences. This evil is in some degree avoided by placing the bond in the middle of the wall so that there is brick-work on each side, and by not putting continued bond for nailing the battens to.

* Bowden's Treatise on Dry Rot, p. 62.

† Idem, p. 68.

‡ Idem, p. 70.

§ Chapman on Preservation of Timber, p. 14.

‖ Idem, p. 73.

¶ 19 Car. II. cap. 3.

But if the powerful lateral pressure of flat arches were avoided, so many ties or bond-timbers would not be necessary. The improper use of arches produces more fractures in buildings than any other cause. Nothing can be more absurd than the construction of the fronts of London houses; they exhibit a continued series of stretchers and ties. Each range of arches is a line of stretchers, and the bond and wall-plates are the ties; and as the arches are close-jointed and well fitted on the outside, but open jointed and indifferently built in the inside, when the building settles it has a strong tendency to bulge outwards. Thus timber ties are necessary to secure an ill-constructed wall, which consequently cannot be more durable than the timber.

As an example of the danger of trusting to timber in supporting heavy stone or brick-work, the failure of the curb of the brick dome of the church of St. Mark, at Venice, may be cited. This dome was built upon a curb of larch timber, put together in thicknesses, with the joints crossed, and was intended to resist the tendency which a dome has to spread outwards at the base. In 1729 a large crack and several smaller ones were observed in the dome. On examination the wooden curb was found to be in a completely rotten state, and it was necessary to raise a scaffold from the bottom to secure the dome from ruin. After it was secured from falling, the wooden curb was removed, and a course of stone, with a strong bond of iron, was put in its place*.

The bad effects resulting from damp walls is still farther increased by hasty finishing. To inclose with plastering and joiners' work the walls and timbers while they are in a damp state, is the most certain means of causing the building to fall into a premature state of decay.

337. There is another cause that affects all wood most materially, which is the application of paint, tar, or pitch, before the wood has been thoroughly dried. The nature of these bodies prevents all evaporation, and confines the internal moisture, which is the cause of sudden decay. Mr. Bramley remarks, that both oak and fir posts were brought into a premature state of decay by their having been painted prior to a due evaporation of their moisture†.

On the other hand, the doors, pews, and carved work, of many old churches, have never been painted, and yet they are often found to be perfectly sound, after having existed above a century‡. In Chester, Exeter, and other old cities, where much timber was formerly used, even for the external parts of buildings, it appears to be sound and perfect, though black with age, and has never been painted.

Mr. Semple mentions an instance of some field-gates made of home fir, part of which, being near the mansion, were painted, while the rest, being in distant parts of

* Rondelet, l'Art de Bâtir, tome iv. p. 256; or Encyclopedie Methodique, Dict. Architecture, art. Coupole.

† Transactions of the Society of Arts, &c. vol. xxi. p. 302.

‡ Rees's Cyclopædia, art. Timber.

the grounds, were not painted. Those which were painted soon became quite rotten, but the others that were not painted continued firm*.

Painted floor-cloths are very injurious to wooden floors, and soon produce rottenness in the floors that are covered with them; as the painted cloth prevents the access of atmospheric air, and retains whatever dampness the boards may absorb, and therefore soon causes decay. Carpets are not so injurious, but still assist in retarding free evaporation.

### PREVENTION OF DECAY.

338. Having now noticed the chief causes of decay, its prevention becomes the next object of inquiry.

When timber has undergone a proper seasoning, in as far as regards the timber, it is the best means of securing it against decay, whatever may be the cause; and, in addition to what I have already said on seasoning (art. 321 to 326) it only remains to add, that the seasoning must be complete to be effectual. The time required for a complete seasoning depends on the size of the pieces; and some correct experiments on this subject would be very desirable, if made on a large scale.

339. But however well timber may be seasoned, if it be employed in a damp situation decay is the certain consequence; therefore, it is most desirable that the neighbourhood of buildings should be well drained, which would not only prevent the rot, but also increase materially the comfort of those who reside in them. The drains should be made water-tight wherever they come near to the walls; as walls, particularly brick walls, readily draw up moisture to a very considerable height. Earth should never be suffered to rest against walls, and the sunk stories of buildings should always be surrounded by an open area, so that the walls may not absorb moisture from the earth. To prevent moisture rising from the foundation, some substance that will not allow it to pass should be used at a course or two above the footings of the walls. Sheets of lead or copper have been used for that purpose. To lay a few courses of slaty stones, that do not absorb much moisture, would be useful; but a better method is to build a few courses in height with Roman cement, instead of common mortar, and upon the upper course to lay a bed of about an inch in thickness of cement. As moisture does not penetrate this cement, it is an excellent material for keeping out wet; and it is also a great improvement to a brick building to stucco it on the outside with any cement that keeps out moisture, as brick absorbs quickly all the moisture that comes in contact with it, and retains it for a length of time.

* Treatise on Building in Water, p. 84.

340. The walls and principal timbers of a building should always be left for some time to dry after it is covered in. This drying is of the greatest benefit to the work, particularly the drying of the walls; and it also allows time for the timbers to get settled to their proper bearings, which prevents after settlements, and cracks in the finished plastering. It is sometimes said, that it is useful, because it allows the timber more time to season; but when the carpenter considers that it is from the ends of the timber that much of its moisture evaporates, he will see the impropriety of leaving it to season after it is framed, and also the cause of framed timbers of unseasoned wood failing at the joints sooner than in any other place. No parts of timbers require seasoning so much as those that are to be joined. Seasoning in the frame is a fatal error in ship-building.

341. Also, when the plastering is finished a considerable time should be allowed for the work to get dry again before the skirtings, the floors, and other joiners' work be fixed. Drying will be much accelerated by a free admission of air, particularly in favourable weather.

When a building is thoroughly dried at first, openings for the admission of fresh air are not necessary where the precautions against any new accessions of moisture have been effectual. Indeed such openings only afford harbour for vermin, as the current of air through them is very seldom capable of carrying off any considerable degree of moisture; for it is well known that air will not move in a horizontal direction without a more considerable change of density than can be obtained in such situations. The roof over the Egyptian Hall, in the Mansion House, London, has a space of two feet in depth all round it for the free circulation of air between the roof and ceiling; and in old Gothic buildings the roofs were generally well ventilated, which must have added much to their durability. But the construction of floors does not admit of the same facilities, and therefore floors are more subject to decay; for, as Mr. Papworth very justly observes, "should the air absorb less moisture from the fungus than the timber affords to its vegetation, the air will then increase the disease, and draw into fuller growth the fungus it has not the power to destroy; but if dry air be admitted in a quantity adequate to cause that absorption, it will necessarily exhaust and destroy the fungus*." But such a quantity of dry air cannot, from the nature of the structure, be made to pass between the timbers of a floor, though sufficient may be admitted to accelerate its decay.

342. In floors next the ground we cannot easily prevent the access of damp, but this should be done as far as possible. All vegetable mould should be carefully removed, and if the situation admits of it, a considerable thickness of dry materials, such as brickbats, dry ashes, &c. but not lime, should be laid under the floor, and over these a coat

* Essay on the Causes of the Dry Rot, p. 43.

of smiths' ashes, or of pyrites, where they can be procured. The timber for the joists should be well seasoned; and it is advisable to cut off all connection between wooden ground floors, and the rest of the wood-work of the building.

343. It is generally imagined that timber may be secured against the rot by impregnating it with substances that resist putrefaction; this opinion has produced many schemes, but no rational hopes of success can be entertained, unless the timber be also well seasoned, and secured as far as possible against moisture. No quick process is likely, yet something might be done where time assisted in giving permanence to the combination.

Common salt (muriate of soda) is found to protect the timber impregnated with it when the proportion of salt is considerable. The large wooden props which support the roofs of the salt mines in Hungary, and are perpetually moistened with salt water trickling down them, are said to have suffered no decay for many centuries*; and the incrustations of salt upon the timbers of vessels employed in carrying salt-fish preserve them a great number of years†. There are, however, strong objections to using solutions of salt, unless it be where it is of no importance whether the wood be dry or wet; for the attraction of salt for moisture would keep the wood continually wet if moisture should be present.

344. Sea water has been found effectual in clearing timber of fungus, by immersing it for several months. A ship called the Eden was cleared of every trace of fungus by remaining eighteen months under water‡. But unless a solution of salt, so strong as to be objectionable from its attraction of water, could be used, there appears to be no well-grounded hope of its being useful; as it is well known that common salt in small quantities assists the decomposition of vegetable matter.

345. Sulphate of iron (commonly called green copperas) appears to be more likely to answer the purpose. Wood boiled for three or four hours in a solution of sulphate of iron, and then kept some days in a warm place to dry, becomes so hard and compact that moisture cannot penetrate it. In the Swedish Transactions it is recommended for preserving the wood of wheel carriages from decay§; and Mr. Chapman observes, that the wooden vessels in which copperas is crystallized become exceedingly hard, and not subject to decay‖. Mr. Chapman strongly recommends immersing timber in a solution of this salt on a large scale, in order to be used for ship-building.

346. Dr. Darwin supposes that the rot in wood might be entirely prevented by soaking dry timber first in lime water, till it has absorbed as much of it as may be, and then, after it is dry, by soaking it in a weak solution of sulphuric acid in water,

* Darwin's Phytologia, p. 520. † Bowden on Dry Rot, p. 162.

‡ Ency. Brit. Supp. art. Dry Rot, p. 682; or Transactions of the Society of Arts, vol. xxxvi. p. 54.

§ Neuman, quoted by Chapman, on Preservation of Timber, p. 22.

‖ Chapman on Preservation of Timber, p. 30.

The acid will combine with the lime in the pores of the timber, and form gypsum (sulphate of lime) and preserve it from decay if kept dry*. The benefit perhaps would not be equivalent to the trouble of this process.

Boiling in alkalies has been proposed; but as the alkalies dissolve and decompose the woody fibre†, this process cannot be attended with advantage.

347. Quicklime, I have already stated (art. 330,) assists putrefaction when aided by moisture. But where a great quantity of quicklime is present, so as to preserve the wood, by its absorption of water, in a perfectly dry state; it hardens the sap, and renders the wood very durable. Of this effect of lime Mr. Chapman had an opportunity of seeing proofs in the vessels employed in the Sunderland lime trade, some of which were forty years old, and very sound‡.

*Repairs of Buildings affected with the Rot.*

348. To cure the rot is very difficult, and would be nearly, if not quite, as expensive a process as to put in anew the timbers affected with it; but when new timber is put in, the old parts and the walls should have every particle of fungus removed from them, or killed by some wash for that purpose. External washes perhaps are not much further useful than so far as they hinder infection; but to produce that effect they are perhaps the best application, because they can be applied with safety. A high degree of heat would destroy all power of reproduction, but it cannot so well be applied; nevertheless, where pieces of wood are not materially injured by the rot, to expose them to a strong heat would destroy all vegetable life in the fungus, and they might then be washed with some of the solutions mentioned below, and used again with perfect safety.

349. A solution of corrosive sublimate (corrosive muriate of mercury) would answer very effectually as a wash. It was proposed by Sir H. Davy. A very weak solution does not produce the desired effect; Chapman says there should be an ounce of corrosive sublimate to a gallon of water, and it should be laid on hot§. No other metallic solution should be mixed with it.

350. A solution of sulphate of copper (commonly called blue vitriol) in the proportion of about half a pound of sulphate of copper to one gallon of water, used hot, makes an excellent wash; and is cheaper than the preceding one.

351. A strong solution of sulphate of iron is sometimes used, but is not so effectual as that of copper; and sometimes a mixture of the two solutions has been used.

* Phytologia, p. 519.

† Dr. Thomson's Chemistry, vol. iv. p. 183.

‡ Chapman on Preservation of Timber, p. 16.

§ Idem, p. 152.

352. Coal tar is said to have been found beneficial, but its strong smell is a great objection to its use; where the smell is not of importance, it would assist in securing new timber that had been previously well dried.

353. Charring new wood can only be expected to prevent infection, as we have seen (art. 330) that decay may begin at the centre, and proceed without ever appearing at the surface of the beam; and therefore if timber be not well seasoned, no permanent good can be obtained from charring.

### *To preserve Wood exposed to the Weather.*

354. When timber is exposed to the alternate action of dryness and moisture, the best means of securing the timber from moisture is the protection of the surface by a coat of some substance that moisture will not penetrate.

The Dutch, for the preservation of their gates, drawbridges, sluices, and other large works of timber, that are exposed to the sun and perpetual injuries of the weather, coat them with a mixture of pitch and tar, upon which they strew small pieces of cockle and other shells, beaten almost to powder, and mingled with sea sand, or the scales of iron beaten small and sifted, which protects them in a most excellent manner*.

Upon common painting sanding is an excellent practice, where it is exposed to the weather; as I have uniformly observed sanded painting to be much more durable than common painting.

Mr. Chapman proposes a composition which possesses the properties of impenetrability to moisture and flexibility. It consists in applying a paint made of sub-sulphate of iron (the refuse of the copperas pans) ground up with any cheap oil, and rendered thin with coal-tar oil, in which a little pitch had been dissolved. In the neighbourhood of Newcastle or Glasgow the refuse of the copperas pans may be easily procured†.

Another method of protecting timber is described by Mr. Semple, which appears to be so well calculated for the purpose, that in cases where it can be applied a better cannot be employed. It is described in his own words as follows: "After your work is tried up, or even put together, lay it on the ground with stones or bricks under it to about a foot high, and burn wood (which is the best firing for that purpose) under it till you thoroughly heat, and even scorch it all over; then, whilst the wood is hot, rub it over plentifully with linseed oil and tar, in equal parts, and well boiled together, and let it be kept boiling whilst you are using it; and this will immediately strike and sink

* Evelyn's Silva, vol. ii. p. 219.

† Chapman on Preservation of Timber, p. 147.

(if the wood be tolerably seasoned) one inch or more into the wood, close all the pores, and make it become exceeding hard and durable, either under or over water*."

No composition should however be applied till the timber has been well seasoned, as to inclose the natural juices of the wood is to render its rapid decay certain.

*Of the Prevention of the Ravages of Worms and Insects.*

355. Besides the decay of its parts, timber is subject to be destroyed by various worms and insects. Some woods are more subject to be destroyed by them than others; such as alder, beech, birch, and, in general, all soft woods, of which the juices are of a saccharine nature.

Against the common worm, oil of spike is said to be an excellent remedy, and the oil of juniper, or of turpentine, will prevent them in some degree. A free use of linseed oil is a good preventive; but these can be applied to small articles only.

Evelyn recommends sulphur which has been immersed in aquafortis (nitric acid) and distilled to dryness, which being exposed to the air dissolves into an oil. The parts to be secured from the worm are to be anointed with this oil, which does not give an unpleasant odour to the wood†.

Lime is an excellent preservative against the worm, and sap-wood should always be impregnated with it when used in a dry situation.

As worms do not attack bitter woods, soaking wood in an infusion of quassia has been tried, which is said to have the desired effect.

356. The bottoms of ships, and timbers exposed to the action of the sea, are often destroyed by the pipe-worm, or *teredo navalis* of naturalists. This creature is very small when first excluded from the egg, but soon acquires a considerable size, being often three or four inches in length, and sometimes increases to a foot in length. Its head is provided with a hard calcareous substance, which performs the office of an auger, and enables it to penetrate the hardest wood. When a piece of wood, constantly under water, is occupied by these worms, there is no sign of damage to be seen on the surface, nor are the worms visible till the outer part of the wood be broken or cut away; yet they lie so near the surface as to have an easy communication with the water by a multitude of minute perforations. They were originally brought from India to Europe.

Wood is eaten by them till it becomes like a honeycomb, yet there is an evident care in these creatures never to injure one another's habitations, for the divisions between the worm holes are entire, though often extremely thin. The fir and alder are the two

* Semple on Building in Water, p. 85.

† Evelyn's Silva, vol. ii. p. 157.

kinds of wood they seem to destroy with the greatest ease, and in these they grow to the greatest size. In oak they make slower progress, and appear smaller, and not so well nourished.

They never touch bitter woods, and in solid or hard woods they make slow progress. Charring the surface of wood is not found to be of any use.

A mixture of lime, sulphur, and colocynth, with pitch, is found to be a protection to boards and the like. And rubbing the wood with poisonous ointments is a means of destroying them *.

Coal tar is also a good protection against their depredations. The pores of the wood should be saturated as far as possible with it; and perhaps corrosive sublimate might be used with advantage, by saturating the wood with a solution of it, and letting it dry before the tar be laid on.

Whale oil is stated to be an effectual remedy, and has been successfully employed †.

357. There is another kind of worm which is very destructive to timber, which Mr. Smeaton observed in Bridlington piers. The wood of these piers, he says, is destroyed by a certain species of worm, differing from the common worm whereby ships are destroyed. "This worm appears as a small white soft substance, much like a maggot; so small as not to be seen distinctly without a magnifying glass, and even then a distinction of its parts is not easily made out. It does not attempt to make its way through the wood longitudinally, or along the grain, as is the case with the common ship worm, but directly, or rather a little obliquely inward. They do not appear to make their way by means of any hard tools or instruments, but rather by some species of dissolvent liquor, furnished by the juices of the animal itself. The rate of progression," he was informed, "is, that a three-inch oak plank will be destroyed in eight years by action from the outside only ‡." Fir is more subject to be destroyed by this worm than oak.

To prevent the destructive effects of these worms, Mr. Smeaton recommended that the timbers of the piers should be squared, and made to fit as close together as possible; to fill all the openings left with tar and oakum, and level the face and cover it with sheathing, as ships are covered.

These worms do not live except where they have the action of the water almost every tide; nor do they live in the parts covered with sand.

The remedies that resist the ship worm would no doubt be effectual against these.

358. The termite or white ant (a species of the genus *termes*, and of the aptera order of insects in the Linnæan system) is represented by Linnæus as the greatest calamity of both Indies, because of the havoc they make in all buildings of wood, in utensils,

* Rees's Cyclopædia, art. Teredo.

† Chapman on Preservation of Timber, p. 43.

‡ Smeaton's Reports, vol. iii. p. 188.

and in furniture; nothing but metal or stone can escape their destructive jaws. They frequently construct nests within the roofs and other parts of houses, which they destroy if not speedily extirpated. The larger species enter under the foundations of houses, making their way through the floors, and up the posts of buildings, destroying all before them*. And so little is seen of their operations, that a well-painted building is sometimes found to be a mere shell.

Corrosive sublimate is highly poisonous to these ants; therefore, to impregnate the timber with a solution of it would prevent their ravages. Arsenic is also very destructive to them; and they do not destroy wood impregnated with oil, particularly essential oils†. Thunberg found cajeput oil effectual in destroying the red ants of Batavia; he used it to preserve his boxes of specimens from them. When ants were put into a box anointed with this oil they died in a few minutes‡.

## *Of the Durability of Timber.*

359. The carpenter who feels any delight in the progress of his art cannot be insensible to the advantage of giving durability to his materials; nor yet be uninterested in any inquiry into the probable extent of their duration. Not that his fame as an artist rests solely on the extent of their duration; for while his productions are worthy of imitation, the remembrance of them will be preserved by the engraver's art as long as there shall be men capable of paying a just tribute to the memory of departed merit. The French army, in 1799, destroyed the celebrated bridge across the Rhine at Schaffhausen; but the fame of Grubenmann the carpenter will long continue; and the form of that excellent specimen of the art will only cease to be remembered when carpentry itself no longer exists§.

It must also be remembered, that to give durability to his materials is one branch of the carpenter's art; and that to be defective in this particular is as much to his discredit, as to be unacquainted with the geometrical or mechanical principles of carpentry.

As examples of the duration of timber, I have collected the following notices; and must, though not without regret, leave the subject to be extended by those who have better means of rendering it more complete.

Of the durability of timber in a wet state, the piles of the bridge built by the

* Rees's Cyclopædia, art. Termite.

† Supp. to Ency. Brit. art. Ant; and Chapman on Preservation of Timber, p. 148.

‡ Thunberg's Travels, vol. ii. p. 300.

§ An excellent plate of this bridge is published by Taylor, Holborn.

Emperor Trajan across the Danube is an example. One of these piles was taken up, and found to be petrified to the depth of three-fourths of an inch; but the rest of the wood was little different from its ordinary state, though it had been driven more than sixteen centuries *.

The piles under the piers of London Bridge have been driven above 600 years, and from Mr. Dance's observations, in 1746, it does not appear that they were materially decayed †; indeed they are now (1819) sufficiently sound to support the massy superstructure. They are chiefly of elm.

360. We have also some remarkable instances of the durability of timber when buried in the ground. Several ancient canoes have been found in cutting drains through the fens in Lincolnshire, which must have lain there for many ages. In the Journal of Science, &c. published at the Royal Institution, one of these canoes is described, which was found at the depth of eight feet below the surface of the ground. It was 30 feet 8 inches long, and 3 feet wide in the widest part, and appears to have been hollowed out of an oak tree of remarkably fine free-grained timber ‡.

Also, in digging away the foundation of old Savoy Palace, London, which was built 650 years ago, the whole of the piles, consisting of oak, elm, beech, and chesnut, were found in a state of perfect soundness; as also was the planking which covered the pile-heads. Some of the beech, however, after being exposed to the air a few weeks, though under cover, had a coating of fungus spread over its surface §.

361. On opening one of the tombs at Thebes, M. Belzoni discovered two statues of wood, a little larger than life, and in good preservation; the only decayed parts being the sockets to receive the eyes. The wood of these statues is most probably the oldest in existence that bears the traces of human labour ||.

A continued range or curb of timber was discovered in pulling down a part of the Keep of Tunbridge Castle, in Kent, which was built about 700 years ago. This curb had been built into the middle of the thickness of the wall ¶, and was no doubt intended to prevent the settlements likely to happen in such heavy piles of building; and therefore is an interesting fact in the history of constructive architecture, as well as an instance of the durability of timber.

In digging for the foundations of the present house at Ditton Park, near Windsor, the timbers of a drawbridge were discovered about ten feet below the surface of the ground; these timbers were sound, but had become black. Hakewell says, that Sir John de Molines obtained liberty to fortify the Manor-house of Ditton, in 1396 **; and

* Buffon, Preuves de la Théorie de la Terre.

† Hutton's Tracts, vol. i. p. 119.

‡ Journal of Science, &c. vol. i. p. 244.

§ Supp. to Ency. Brit. art. Dry Rot, p. 684.

|| Quarterly Review, vol. xix. p. 422; or Supp. to Ency. Brit. art. Dry Rot.

¶ King's Observations on Ancient Castles, p. 99.

** History of Windsor, p. 329.

it is most probable the drawbridge was erected soon after that time; and accordingly the timber had been there about 400 years.

362. The durability of the framed timbers of buildings is also very considerable. The trusses of the old part of the roof of the Basilica of St. Paul, at Rome, were framed in 816, and were sound and good in 1814, a space of nearly a thousand years. These trusses are of fir*.

The timber-work of the external domes of the church of St. Mark, at Venice, is more than 800 years old, and is still in a good state†.

The inner roof of the Chapel of St. Nicholas, King's Lynn, Norfolk, is of oak, and was constructed about 450 years ago‡.

Daviller states, as an instance of the durability of fir, that the large dormitory of the Jacobins' Convent, at Paris, had been executed in fir, and lasted 400 years§.

The timber roof of Crosby Hall, in London, was executed about 360 years ago‖; and the roof of Westminster Hall, which is supposed to be of chesnut, is now above 300 years old.

The rich carvings, in oak, which ornamented the ceiling of the king's room in Stirling Castle, are many of them still in good preservation. It is nearly 300 years since they were executed, and they remained in their original situation till a part of the roof gave way, in 1777, when the whole was removed, and has since been dispersed among the collectors of curious relics of old times¶.

Moreton Hall, in Cheshire, where "the staircase winds round the trunk of an immense oak tree," and the building itself is chiefly constructed of wood, has now existed 250 years**.

And Mr. Britton describes an old house at Islington, constructed chiefly of wood, which he has ascertained to be about 200 years old††.

363. Other notices of extraordinary durability will be found in the descriptions of the different kinds of wood. But enough already has been collected to show that timber is very durable where nothing more than ordinary means have been used to render it so; that is, nothing more than judicious selection and good seasoning.

Every permanent support should be a good and sound piece of timber; inferior kinds should be used for temporary purposes, and where no strain occurs, and consequently where they can be easily renewed without injury to the strength of the building.

* Rondelet, l'Art de Bâtir, tome iv. p. 168.

† Idem, tome iv. p. 259.

‡ Britton's Archit. Antiq. vol. iii. p. 58.

§ Daviller, Cours d'Architecture, tome ii. art. Bois.

‖ Idem, vol. iv. p. 137.

¶ Lacunar Strevelinense, p. 4. This work is a collection of engravings of the carvings; and some of the borders might furnish useful hints to artists.

** Britton's Archit. Antiq. vol. ii. p. 83.

†† Idem, vol. ii. p. 85.

Mr. Barrow, in writing on this subject, very judiciously remarks, "that the felling of timber while young and full of vigour, making use of the sap-wood, and applying it to ships and buildings in an unseasoned state, have no doubt contributed to make the disease of dry rot infinitely more common and extensive than it was in former times, when our ships were 'hearts of oak,' and when, in our large mansions, the wind was suffered to blow freely through them, and a current of air to circulate through the wide space left between the panneled wainscot and the wall. In those old mansions which yet remain, and in the ancient cathedrals and churches, we find nothing like dry rot, though perhaps

> ........................ 'perforated sore
> And drilled in holes, the solid oak is found
> By worms voracious eaten through and through *.'"

364. In regard to the durability of different woods, the most odoriferous kinds are generally esteemed the most durable; also woods of a close and compact texture are generally more durable than those that are open and porous; but there are exceptions, as the wood of the evergreen oak is more compact than that of the common oak, but not near so durable.

Sir H. Davy has observed, that, "in general, the quantity of charcoal afforded by woods offers a tolerably accurate indication of their durability; those most abundant in charcoal and earthy matter are most permanent; and those that contain the largest proportion of gaseous elements are the most destructible. Amongst our own trees," he adds, "the chesnut and the oak are pre-eminent as to durability, and the chesnut affords rather more carbonaceous matter than the oak †." But we know from experience, that red or yellow fir is as durable as oak in most situations, though it produces less charcoal by the ordinary process. I have added, for the information of the reader, the following table of the quantity of charcoal afforded by 100 parts of different woods.

* Supplement to Encyclopædia Britannica, art. Dry Rot.

† Agricultural Chemistry, p. 254, 8vo. edit.; p. 221, 4to. edit.

*Table of the Quantity of Charcoal in a hundred Parts of Wood, according to different Experimentalists.*

| Kind of wood. | Watson*. | Mushet†. | Proust‡. | Rumford‡. |
|---|---|---|---|---|
| Oak, dry .......... | 22·92 | 22·6 | 19 | 43 |
| Chesnut .......... | | 23·2 | | |
| Mahogany ........ | 20·82 | 25·4 | | |
| Walnut ........... | 26·04 | 20·6 | | |
| Elm ............. | | 19·5 | | 43·27 |
| Beech ........... | | 19·9 | | |
| Fir .............. | 15·62 | | | 44·18 |
| Norway pine ...... | | 19·2 | | |
| Pine ............. | | | 20 | |
| Scotch pine ....... | | 16·4 | | |
| Ash .............. | 17·71 | 17·9 | 17 | |
| Poplar ........... | | | | 43·57 |
| Lime ............ | | | | 43·59 |
| Birch ............ | | 17·4 | | |
| Sycamore ......... | | 19·7 | | |
| Sallow ........... | | 18·4 | | |

In Count Rumford's experiments a longer period was allowed for the process; and, in consequence, his results represent more nearly the real quantities of carbon in each wood than the others. But even according to the common process it does not appear that the proportion of charcoal is a satisfactory criterion of the durability.

365. An experiment to determine the comparative durability of different woods is related in Young's Annals of Agriculture, which will be more satisfactory than any speculative opinion; and it is much to be regretted that such experiments have not been oftener made.

"Inch-and-half planks of trees from thirty to forty-five years' growth, after ten years standing in the weather, were examined and found to be in the following state and condition:

Cedar, perfectly sound.
Larch, the heart sound, but sap quite decayed.
Spruce fir, sound.
Silver fir, in decay.
Scotch fir, much decayed.
Pinaster, quite rotten.
Chesnut, perfectly sound.
Abele, sound.
Beech, sound.
Walnut, in decay.
Sycamore, much decayed.
Birch, quite rotten §."

* Chemical Essays, vol. iii. p. 27.

† Philosophical Magazine, vol. ii. p. 183.

‡ Dr. Thomson's System of Chemistry, vol. iv. p. 185.

§ Annals of Agriculture, vol. vi. p. 256.

This shows at once the kinds that are best adapted to resist the weather; but even in the same kind of wood there is much difference in the durability; and the observation is as old as Pliny, "that the timber of those trees which grow in moist and shady places is not so good as that which comes from a more exposed situation, nor is it so close, substantial, and durable*;" and Vitruvius has made similar observations†.

Also split timber is more durable than sawn timber, for in splitting the fissure follows the grain, and leaves it whole, whereas the saw divides the fibres, and moisture finds more ready access to the internal parts of the wood. Split timber is also stronger than sawn timber, because the fibres being continuous, they resist by means of their longitudinal strength; but when divided by the saw, the resistance often depends upon the lateral cohesion of the fibres, which is in some woods only one-twentieth of the direct cohesion of the same fibres. For the same reason whole trees are stronger than specimens, unless the specimens be selected of a straight grain, but the difference in large scantlings is so small as not to be deserving of notice in practice.

Before proceeding to describe the particular woods, it will be necessary to explain the differences in their structure, and to make the reader acquainted with the means that have been adopted to ascertain their properties.

## OF THE STRUCTURE AND CLASSIFICATION OF WOODS.

366. To the experienced eye of a workman the general appearance of each variety of wood has become so familiar, and its most obvious characters are so strongly impressed on his memory, that he readily knows them one from another; but, nevertheless, the notice of some characters that are peculiar to certain kinds of woods may be of use, especially to young men, who will find both information and amusement in making collections of specimens, in examining their properties, and in rendering themselves familiar with their uses‡.

In a section of a tree it clearly appears that the wood is composed of separate layers, or rings, regularly disposed round the pith, which is in general nearly in the centre of the tree; but the thickness of these layers is seldom if ever perfectly regular,

* Pliny, as quoted by Evelyn, Silva, vol. i. p. 87.

† Vitruvius, book ii. chap. ix.

‡ I make it a rule to preserve a specimen of each piece that I make an experiment upon; such a collection is invaluable as an appendage to tables of experiments.

When examined by a magnifier, the wood appears to consist of fine divisions, like rays, spreading from the pith to the bark, with pores between them, often empty, but sometimes filled with some kind of vegetable matter. In the resinous woods most of the pores are filled.

Besides the fine divisions, which are often scarcely to be distinguished by the naked eye, there are, in some woods, other divisions that are larger; like larger rays passing from the pith to the bark, they are generally of a light silvery colour, and are called the silver grain, or larger transverse septa. When a piece of wood is cut so as to pass obliquely through the larger septa or silver grain it produces that fine flowered appearance so well known in the oak.

The fine divisions, or lesser transverse septa, are common to all woods except the palm, though in some they are not very distinct; but there are only some kinds that have the larger septa, or silver grain*; therefore this forms a natural character for distinguishing the kinds of wood. And they may be divided into two classes, one that has, and the other that has not, the larger septa or silver grain.

Again, in some woods each annual layer or ring seems to be nearly uniform in its texture, and the line of separation between the layers is not very distinct, being so indistinct in some woods as to be "as it were shadows of circles, nothing real." Mahogany is an example of this structure; and the robinia caragna of Hill is of this kind†.

But in other woods one part of the layer is nearly compact, and the rest of it presents the appearance of a circle of empty pores; of which we have an example in the ash. This structure is remarkably distinct in Hill's section of the arbutus‡.

There is a third kind, in which nearly all the pores appear to be filled with resinous or gummy matter; and one part of the layer consists of a compact, hard, and dark-coloured substance, the other part is lighter coloured and softer. All the resinous woods are of this kind.

367. According to these distinctions the arrangement of the following table is made.

* As the term silver grain is used to denote both the smaller and larger septa, I shall follow the example of Mr. Ellis (Vegetable Anatomy, Supplement to the Encyclopædia Britannica, p. 332) and employ the terms larger transverse septa, and lesser transverse septa. I would rather have used the term silver grain; but if so, it must have been in a restricted sense, and in such cases new terms are less likely to mislead.

† Hill on the Construction of Timber, p. 136. ‡ Idem, p. 137.

| | Class | Division | Kinds |
|---|---|---|---|
| WOODS. | CLASS I.—With larger transverse septa. | *Division* 1.—Very distinct annual rings, one side porous, the other compact. | Oak. |
| | | *Division* 2.—Annual rings not very distinct, and their texture nearly uniform. | Beech. Alder. Plane. Sycamore. |
| | CLASS II.—No larger transverse septa. | *Division* 1.—Annual rings very distinct, one side porous, the other compact. | Chesnut. Ash. Elm. False acacia. |
| | | *Division* 2.—Annual rings not very distinct, and their texture nearly uniform. | Mahogany. Walnut. Teak. Poplar. |
| | | *Division* 3.—Annual rings very distinct, pores filled with resinous matter; one part of the ring hard and heavy, the other soft and lighter coloured. | Cedar of Lebanon. Larch. Yellow fir. White fir. American pine. Cedar. |

The only properties of wood that seem to require explanation are the cohesive force, the modulus of elasticity, the stiffness, the hardness, and the toughness.

368. The *cohesive force* of a bar or beam is equal to the power or weight that would pull it asunder in the direction of its length. The weight that would pull asunder a bar of an inch square of different kinds of wood has been ascertained by experiments. Of these experiments I have taken the highest and lowest result for each kind of wood. Experiments have been made by Muschenbroek*, Emerson†, Rondelet‡, Anderson, and Barlow§.

369. The *modulus of elasticity* is the measure of the elastic force of any substance. Dr. Thomas Young has by means of it given some very elegant demonstrations of the laws of resistance‖. As it is the measure of the elastic force, its use must be evident when it is considered that it is only the elastic force of timber that is employed in

* Intro. ad Phil. Nat. tom. i. p. 414.

† Mechanics, 4to. edit. sect. viii.

‡ L'Art de Bâtir, tome iv.

§ Essay on the Strength of Timber, &c.

‖ Lectures on Natural Philosophy, vol. ii.

resisting the usual strains in carpentry; and the learned reader will readily perceive, that the constant numbers in my rules for the stiffness of timber have for one of their elements the modulus of elasticity.

By means of the modulus of elasticity the comparative *stiffness* of bodies can be ascertained. For instance, its weight for cast iron is 18,240,000 pounds, and its weight for oak is 1,714,500 pounds. Hence it appears that the modulus for cast iron is 10·6 times that of oak, and therefore a piece of cast iron is 10·6 times as stiff as a piece of oak of the same dimensions and bearing.

370. A *hard* body is that which yields least to any stroke or impressive force; and it may be shown, by the principles of mechanics, that in uniform bodies the degree of yielding is always proportional to the weight of the modulus of elasticity; therefore, a table containing the weights of the modulus of elasticity of such bodies shows also their relative hardness and stiffness.

The relative hardness is determined with considerable accuracy by means of the modulus of elasticity; but the methods used for ascertaining the hardness of mineral bodies is very defective; and the method proposed by Dr. O. Gregory*, from the theory of percussion, is not susceptible of any tolerable degree of accuracy, from the difficulty of making correct experiments.

As the hardness follows the same laws as the stiffness, cast iron is 10·6 times as hard as oak. But it is necessary to inform the reader, that when the substance is not uniform, the hardness thus found is that of the hardest part. Thus, in fir, it is the darker part of the annual ring that is the hardest, and which determines the extent to which a beam will bend without fracture. Dry wood is harder than green, consequently it is more difficult to work. The labour of sawing dry oak is to that of sawing green as 4 is to 3†, nearly.

371. In respect to the *toughness* of woods, that wood is the toughest which combines the greatest degree of strength and flexibility; hence that wood which bears the greatest load, and bends the most at the time of fracture, is the toughest. From the data obtained in the course of my experiments, the comparative toughness has been ascertained; except in a few instances, where I had not specimens sufficiently long for experiments. In such cases Mr. Barlow's experiments have been calculated from.

372. The opposite to hardness is softness, the opposite to toughness is brittleness, and the opposite to stiffness is flexibility; therefore, when the hardness, toughness, or stiffness of a wood is expressed by a low number, it may be considered to have the opposite quality.

373. I have made oak the standard of comparison, and have considered its strength, toughness, and stiffness, each to be 100; and in so doing, the mean strength of oak is

* Treatise on Mechanics, vol. i. art. 348.

† Belidor's Architecture Hydraulique, tome i. p. 342.

taken at 11,880 pounds per square inch, and its modulus of elasticity at 1,714,500 pounds for a square inch.

Having thus laid before the reader the means adopted for arriving at the properties of the woods, I scarcely need say, that it is those properties which determine its fitness for the different purposes of carpentry. In some cases stiff woods are required, as in the joists and rafters of a building; in other cases tough woods should be employed, as for the shafts of carriages; and in other cases strength is necessary, as in ties, and other timbers strained in the direction of their length.

Tough woods, which are also hard, are the most difficult to work, especially if cross grained; on the contrary, brittle woods work easily; and hard woods preserve the best surface.

And, in general, where straightness is desirable, stiff woods should be preferred; where sudden shocks are to be sustained, tough woods are the best; where little strength is required, but much labour is to be put upon it, a brittle wood is desirable; and where a fine surface is to be preserved, a hard wood should be chosen: so that it is not in carpentry alone that these researches will be useful, for they are equally applicable to any art where timber is employed.

## DESCRIPTION OF WOODS.

### CLASS I.

374. The first class contains all woods that have larger transverse septa (silver grain.) The woods of this class are compact, hard, and heavy; never very deep coloured, the oak being the darkest coloured of the class; they are nearly free from smell, and never resinous.

This class is formed into two divisions; one containing those woods in which the annual rings are distinctly porous on one side, and compact, or nearly compact, on the other; the other division contains those in which the annual rings are sensibly uniform, and only to be distinguished by a difference of colour.

### DIVISION I.

375. In this division I have only observed one species, the oak, which is universally allowed to be the best of woods.

## I. OAK.

376. Of the oak (the *Quercus* of botanical writers) there are several species, which produce valuable timber. Vitruvius enumerates five kinds, viz. the esculus, the cerrus, the quercus, the suber, and the robur; the timber of each being distinguished by its peculiar properties*: but it would be difficult to identify some of the kinds mentioned by him with the species described by botanical writers. Vitruvius, by his observations, shows that the qualities of the different species were attended to; and they must also have been well understood by the Gothic builders in this country, for in the roofs and beams of most of their buildings we find a very superior kind of oak, which sometimes closely resembles, and is often mistaken for, chesnut. (See art. 384.) I have heard this kind of oak called the "Irish oak." Evelyn commends the Irish oak "for resisting the worm†;" but to what species of oak he alludes I have not been able to determine.

At the present time the Sussex oak is esteemed the best which England affords; its superiority, according to Marshall, is chiefly to be attributed to the nature of the soil‡; perhaps also in some degree to good management, for the management of woods makes a considerable difference in the value of the timber. Miller states, that he observed many large trees of the kind with long stalks to the acorns in the wilds of Kent and Sussex §. From this it would appear that the common, and consequently the valuable Sussex oak, is not of that species; but whether it be or not I have not been able to ascertain.

In general the English oak is spoken of by practical men as though there were but one species, and no difference in the quality of the wood, except that produced by soil and situation; but two distinct species have been long known to English botanists ||; and it appears from the observations and inquiries I have made, that the kinds which are common in different districts are different species. I have not been able to extend my observations on this point so far as I was desirous of doing; but as the different species differ materially in their properties, it is of national importance that the best species for ship-timber should be most commonly cultivated; therefore I hope the investigation will be continued by some one more competent to the task.

Common British oak (*Quercus robur* ¶) is found throughout the temperate parts of

* Lib. ii. cap. ix.

† Silva, Hunter's edit. vol. ii. p. 222.

‡ Rural Economy of the Southern Counties, vol. ii. p. 109.

§ Gardener's Dictionary, art. Quercus.

|| See Ray's Sinopsis Methodica Stirpium Britannicarum, p. 440.

¶ This tree is the *quercus pedunculata* of Willdenow and some other botanists: Sir J. E. Smith makes it *quercus robur*, and states, that Linnæus, as well as the British botanists, have always considered it to be the robur; I have

Europe, and is that which is most commonly met with in the woods and hedges of the south of England.

The leaves of this species are irregularly sinuated, with short, or scarcely any foot-stalks; the acorns have long stalks. In favourable situations this species attains an immense size. A fine healthy tree, now growing (1820) in the grounds of Earl Cowper, at Panshanger, Herts, measures nearly 18 feet in circumference, at 5 feet from the ground; and the whole height of the tree exceeds 75 feet.

The wood of this species has often a reddish tinge; the larger septa are always very numerous, producing large flowers; the grain is tolerably straight and fine, and it is generally free from knots; sometimes closely resembling foreign wainscot. It splits freely, and makes good laths for plasterers and slaters; and it is decidedly the best kind of oak for joists, rafters, and for any other purposes where stiff and straight grained wood is desirable.

The sessile-fruited oak, bay-oak of Bobart, Norwood oak of Martyn (*Quercus sessiliflora*) is a native of the woods and hedges of the temperate parts of Europe, and appears to have been first noticed as a distinct species in this country by Mr. Bobart, in Bagley Wood, and near Newbury, in Berkshire*. It has been observed by Miller, near Dulwich, in Surry; and it appears to be the common oak of the neighbourhood of Durham, and perhaps generally of the north of England.

A few trees of this kind have been observed by Mr. Atkinson, in the grounds of Thomas Hope, Esq. near Dorking, Surry; and there are also some very fine trees in the Earl of Mansfield's grounds at Kenwood†, where I had an opportunity of comparing the trees of the two species; but could not observe any difference in their growth or general form, except that the sessile-fruited oak had a more graceful appearance, which renders it superior as an ornamental tree.

The leaves have longish footstalks, often nearly an inch long, and they are more regularly and less deeply sinuated than those of the robur. The acorns sit close to the branches, having very short or scarcely any stalks.

therefore followed his authority. It also appears to be the *robur* of Vitruvius, for he states that the robur is less subject to warp than the quercus (book ii. chap. iii.;) now this is precisely the case with the two English oaks, as the wood of the robur of Smith is much less subject to warp than that of the sessiliflora. Again, the description given by Vitruvius of the wood of the quercus (in book ii. chap. ix.) agrees in every thing with the properties of that of the sessile-fruited oak; and as he describes the wood only, it is by it alone that the species is to be known. Perrault (in his notes on Vitruvius) and Evelyn (in his Silva) apply the name robur to the sessile-fruited oak: but had either of these writers known that the wood of the sessile-fruited oak is more flexible than that of the other kind, they would not have done so; for it appears to have been merely the import of the name that they had in view.

* Ray's Sinopsis, &c. p. 440.

† These trees were first pointed out to me by my brother, whose assistance in collecting and examining specimens of the leaves, fruit, and wood of these and other trees has been very useful.

The wood is of a darker colour than that of the robur, and the larger septa are not so abundant; sometimes there are very few septa. The smoothness and gloss of the grain makes it resemble that of chesnut. It is heavier, harder, and more elastic, than the wood of the robur, and is very subject to warp and split in seasoning. It is very tough and difficult to split, therefore not fit for laths. This is most probably the reason that oak laths are so seldom used in the north of England. In respect to the comparative durability of the woods of the two species, it is a question that requires to be investigated. It appears, as far as can be determined from the structure of the wood, that the fine oak found in old Gothic roofs is of the sessile-fruited kind; at the same time it must be owned, that our means of judging are not so satisfactory as to enable us to decide on this point with certainty; but we know that the old oak is very durable.

The strength, elasticity, toughness, and hardness of the sessile-fruited oak render it superior for ship-building, but it is both heavier and more difficult to work than the robur; how far they may differ in durability remains to be determined. The wood for the old *Sovereign of the Seas* was from the north*: is it not probable that the greater part of it was of the sessile-fruited oak? The hardness of the timber "when taken in pieces after forty-seven years' service" is in favour of this conjecture.

In order to make experiments on the two species, when grown at the same place, and nearly of the same age, I was supplied with specimens by Mr. Atkinson. These specimens were from trees grown in the grounds of Thomas Hope, Esq. at the Deepdene, near Dorking, Surry, which were directed to be cut by Mr. Hope for the express purpose of comparing the woods.

The trees were cut a little before the fall of the leaf, and being cut into small scantlings, after drying two months they were submitted to experiment.

The following table shows the results of trials on two pieces, each piece an inch square, and sustained by supports 24 inches apart, the weight being applied in the middle of the length.

| Species of oak. | Specific gravity. | Weight of a cubic foot in pounds. | Comparative stiffness or weight that bent the piece seven-twentieths of an inch. | Comparative strength or weight that broke the piece. |
|---|---|---|---|---|
| | | | pounds. | pounds. |
| Quercus robur ....... | ·807 | 50·47 | 167 | 322 |
| Quercus sessiliflora.... | ·879 | 54·97 | 149 | 350 |

Both these specimens broke short without splitting, therefore these experiments offer a very fair view of the properties of the two species. The sessiliflora bent considerably

* Supplement to Encyclopædia Britannica, art. Dry Rot, p. 684.

more at the time of fracture than the robur, but it could not be measured with that correctness which is necessary to render such data useful.

The following table contains the values of the cohesive force, and modulus of elasticity, calculated from the above experiments.

| Species of oak. | Cohesive force of a square inch in pounds. | Weight of modulus of elasticity in pounds for a square inch. | Comparative toughness. |
|---|---|---|---|
| Quercus robur .......... | 11,592 | 1,648,958 | 81 |
| Quercus sessiliflora ...... | 12,600 | 1,471,256 | 108 |

These pieces were hastily and therefore imperfectly seasoned; but as they were treated exactly alike this would not affect the comparison.

There is another species called the Durmast oak, which is a native of France and the south of England; its wood is not so strong nor of so firm a texture as the English oak, and it retains its foliage much later.

The Austrian oak is a taller tree than the English oak, but the wood is whiter, softer, and less valuable.

Of the American species the chesnut-leaved oak is a tall tree, remarkable for the beauty of its form: the wood is coarse grained, but is very serviceable, and is much used for wheel carriages.

The mountain red oak (*Quercus rubra*) is a native of Canada, and the country west of the Allegany Mountains; it is called the red oak from the leaves changing to a red or purple colour before they fall off. It is a large and fine tree, of 90 or 100 feet in height, and of rapid growth; the wood is useful for many purposes, but it is light, spongy, and not very durable.

The white oak (*Quercus alba*) so called from the whiteness of its bark, is a native of the woods from New England to Carolina, and acquires an immense size in some of the middle states. Its wood is tough and pliable, and it is preferred to all others in America for both house and ship carpentry, being much more durable. It is less durable than British oak, but it is of a quicker growth.

The blunt-lobed iron oak is another of the American species that produces very valuable ship-timber; the wood is hard and not liable to decay, and is preferred for fencing. It is found in most of the upland forests from Canada to Florida, and is a tree of 60 or 70 feet in height.

The species of the Riga oak, so valuable on account of the straightness of its grain and freedom from knots, does not appear to have been determined: neither have I been able to find from what species the Dutch wainscot is obtained; it is grown in the forests of Germany, and floated down the Rhine.

According to Hassenfratz, the mean size of the trunk of the

| | | |
|---|---|---|
| Common oak is ...... | 45 feet in length and | 32 inches diameter. |
| White American oak .. | 58 .............. | 35 |
| Red American oak ... | 48 .............. | 32 |

Oak of a good quality is more durable than any other wood that attains a like size. Vitruvius says, it is of eternal duration when driven into the earth; and it is well known to be extremely durable in water; and in a dry state it has been known to last nearly 1000 years. The more compact it is, and the smaller the pores are, the longer it will last; but the open, porous, and foxy-coloured oak, which grows in Lincolnshire and some other places, is not near so durable. Mr. Chapman very justly observes, that the heart of such oak is scarcely superior to the sap of better kinds.

The chief use of oak is for ship-timber: the consumption of oak for the construction and repair of the British navy in 1788 exceeded 50,000 loads of timber*. It is also useful for most of the purposes of the carpenter, and particularly in situations where it is exposed to the weather. It makes the best wall-plates, ties, templets, king posts, and indeed it is best suited for every purpose where its warping in drying and its flexibility do not render it objectionable; but, as Vitruvius has observed, it is very subject to twist and occasion cracks in the work it is employed in.

The colour of the oak is a fine brown, and is familiar to every one; it is of different shades; that inclined to red is the most inferior kind of wood. The larger transverse septa are in general very distinct, producing beautiful flowers when cut obliquely. Where the septa are small and not very distinct the wood is much the strongest. The texture is alternately compact and porous, the compact part of the annual ring being of the darkest colour, and in irregular dots, surrounded by open pores, producing beautiful dark veins in some kinds, particularly in pollard oaks.

It has a peculiar smell, and the taste is slightly astringent. It contains gallic acid, and is blackened by contact with iron when it is damp.

The young wood of English oak is very tough, often cross grained, and difficult to work. Foreign wood and that of old trees is more brittle and workable.

Oak warps and twists much in drying, and shrinks about one-thirty-second part of its width in seasoning, according to Mr. Couch's experiments.

The cohesive force of oak varies from 7850 to 17,892 pounds per square inch. The mean of Mr. Barlow's experiments is 10,000 pounds. I have taken 11,880 as a standard to compare with the other woods, being the result of an experiment on a specimen of a mean quality.

The weight of the modulus of elasticity for a square inch is 1,714,500 pounds, from a mean of various specimens.

* Report of Commissioners of Woods and Forests, for 1812, p. 22.

The weight of a cubic foot of different kinds is as under:

English oak, from ........... 45 to 58 pounds, seasoned.
Riga oak .................... 43 to 54
Red American oak ........... 37 to 47
White American oak ......... 50 to 56
Adriatic oak ................ 58 to 68

Representing the strength, stiffness, and toughness of the common English oak (*quercus robur*) each by 100, it may be compared with the other kinds as under :

| | Common English oak. | Riga oak. | American oak. | Dantzic oak. |
|---|---|---|---|---|
| Strength ........ | 100 | 108 | 86 | 107 |
| Stiffness ........ | 100 | 93 | 114 | 117 |
| Toughness ...... | 100 | 125 | 64 | 99 |

It is necessary to observe, that the specimens of Riga and Dantzic oak were of the best quality.

Rees's Cyclopædia, art. Quercus; Barlow's Essay on the Strength of Timber; Rondelet, L'Art de Batir; Vitruvius, book ii. and vii.; Chapman on Preservation of Timber; and Lambert's Travels in Canada, vol. i.

### DIVISION II.

377. In the second division there are several species; I have described only four; the beech, alder, plane, and sycamore. The woods of this division are very uniform in their texture, and very durable in water; they are useful for piles and planking in wet situations, but not applicable to other kinds of carpenters' work. Woods of this division do not warp so much as those of the first division.

#### 1. Beech.

378. Of the beech tree, the *Fagus sylvatica* of botanists, there is one species, the common beech; the difference in the wood proceeding, according to Miller, from the difference of soil and situation; but owing to this difference the wood is distinguished by the names brown or black, and white beech.

The beech is common in Europe, especially on a rich chalky soil; a considerable quantity is grown in the southern parts of Buckinghamshire; there is one wood of beech trees in the parish of Wycombe containing 700 acres. On the southern range of chalk hills the beeches are very fine, particularly near Walberton in Sussex. The best beeches grow on a good soil, more dry than moist; and the wood is whiter than that of those grown in damp valleys, which loses its strength in drying and becomes brittle. The mean size of the trunk of the beech tree, according to Hassenfratz, is about 44 feet in length and 27 inches in diameter.

Beech is durable when constantly immersed in water, but damp soon destroys it. In a dry state it is more durable, but is soon injured by worms, whether it be in a damp or in a dry state. Duhamel observes, that water-seasoned beech is much less subject to worms than that seasoned in the common way; and Ellis says, to preserve it from worms, it ought to be cut about a fortnight after midsummer, and planked immediately; then the planks should be put in water about ten days, and afterwards dried.

Beech is not useful in building, because it rots so soon in damp places, but it is useful for piles in situations where it will be constantly wet; and it is very useful for various tools, for which its uniform texture and hardness render it superior to any other wood: it is also much used for furniture, and great quantities are brought to London in boards and planks. Before cast iron was introduced much beech was used for railways for the collieries about Newcastle.

The colour of beech is a whitish brown, of different shades; the darker kind is called brown, and sometimes black beech; the lighter kind is called white beech. The texture is very uniform; the larger septa are finer and do not extend so far in the length of the wood as in oak, therefore the flowers are smaller. The annual rings are rendered visible by being a little darker on one side than the other. It is very uniformly porous, and might be easily made to imbibe some ingredient that would prevent the worms destroying it. (See art. 355.)

It has no sensible taste or smell, it is not very difficult to work, and may be brought to a very smooth surface.

The white kind is the hardest, but the black is tougher; and Evelyn says it is more durable than the white.

The cohesive force of a square inch of beech varies from 6070 to 17,000 pounds; the weight of its modulus of elasticity is about 1,316,000 pounds; the weight of a cubic foot dry varies from 43 to 53 pounds. The higher numbers are from Muschenbroek, both in cohesive force and weight, and they are certainly much above any I have observed, as well as much above those of any other writer: about 12,000 pounds is its mean cohesive force.

| | | |
|---|---|---|
| Representing the strength of oak by | 100, that of beech will be .... | 103 |
| stiffness of oak by | 100, ...................... | 77 |
| toughness of oak by | 100, ...................... | 138 |

Hence it appears that oak is superior in stiffness, but neither so strong nor so tough.

Miller's Gardener's Dictionary; Rees's Cyclopædia; Duhamel, Transport des Bois; Evelyn's Silva; Ellis's Timber Tree Improved; Rondelet, l'Art de Batir; Barlow's Essay; Marshall's Southern Counties, vol. ii.

## 2. ALDER.

379. The alder tree is the *Betula alnus* of botanists, a native of Europe and Asia, that grows in wet grounds and by the banks of rivers. The tree seldom exceeds 40 feet in height.

The wood is extremely durable in water or wet ground. Vitruvius has remarked, that in a wet state it will sustain the weight of very heavy piles of building without risk of accident; and that the whole of the buildings at Ravenna, which is situate in a marsh, were founded upon piles of this wood. Evelyn says, he finds they used it under that famous bridge at Venice, the Rialto, which was built in 1591, or 228 years ago. But it soon rots when exposed to the weather, or to damp; and in a dry state it is much subject to worms.

On account of the durability of alder in water, it is esteemed valuable for piles, planking, sluices, pumps, and, in general, for any purpose where it is constantly wet. And for such purposes it has been much cultivated in Holland and Flanders. It is also used for turner's wares and other light purposes. It was used by our ancestors for scaffolding *.

The colour of alder is reddish yellow, of different shades, and nearly uniform. The texture is very uniform, with larger septa of the same colour as the wood, therefore not very distinct, nor producing sensible flowers.

It is soft, and works very easily; would cut well in carving, and make very good models for casting from.

The cohesive force of a square inch of alder varies from 5000 to 13,900 pounds; its modulus of elasticity is 1,086,750 pounds for a square inch; and a cubic foot weighs from 34 to 50 pounds in a dry state.

* Britton's Architectural Antiquities, vol. iii. p. 31.

| | | |
|---|---|---|
| Representing the strength of oak by | 100, that of alder will be .... | 80 |
| stiffness of oak by | 100, ...................... | 63 |
| toughness of oak by | 100, ...................... | 101 |

Evelyn's Silva; Vitruvius, book ii. chap. ix. and book iii. chap. iii.

### 3. Plane Tree.

380. Of the plane tree there are several species. The most common are the oriental plane and the occidental plane.

The oriental plane (*Platanus orientalis*) is a native of the Levant, and other eastern countries, and is considered one of the finest of trees. It attains about 60 feet in height, and has been known to exceed eight feet in diameter. Its wood is much like beech, but more figured, and is used for furniture and things of a like nature. The Persians employ it for their furniture, doors, and windows.

The occidental plane (*Platanus occidentalis*) is a native of North America, and is perhaps one of the largest of the American trees; on the fertile banks of the Ohio and Mississippi some of the trees exceed twelve feet in diameter. It is sometimes called water-beech, and sycamore; but the wood called sycamore in this country is a species of maple. (See art. 381.) The wood of the occidental plane is harder than that of the oriental kind; but the occidental is the most common in Britain, and to it only the rest of this article applies.

The colour of the wood of the plane tree is nearly the same as that of beech, and it also closely resembles it in structure; it differs in the larger septa, as in the plane the septa are more numerous, producing very beautiful flowers when properly cut. It works easily and stands very well.

The cohesive force of a square inch is about 11,000 pounds; its modulus of elasticity is 1,343,000 pounds per square inch; and it weighs from 40 to 46 pounds per cubic foot, when dry.

| | | |
|---|---|---|
| Representing the strength of oak by | 100, that of plane tree will be .. | 92 |
| stiffness of oak by | 100, ...................... | 78 |
| toughness of oak by | 100, ...................... | 108 |

The wood of the occidental plane is very durable in water, and on that account the Americans use it for wooden quays in preference to any other kind.

Rees's Cyclopædia; Michaux's Travels, p. 7 and 86; Olivier's Travels, vol. i. p. 75.

### 4. Sycamore.

381. The sycamore or great maple (*Acer pseudo-platanus*) generally called the plane tree in the north of England, is a native of the mountains of Germany, and is very common in Britain.

It is a large tree, and of quick growth; it thrives well near the sea. According to Hassenfratz, the mean size of its trunk is about 32 feet in length, and 29 inches in diameter. Evelyn says, that in Germany they have a better variety than the one which grows in Britain.

The wood is durable in a dry state when it can be protected from worms, but it is equally as subject to be destroyed by them as beech. It is used chiefly for furniture, and the white wood of this tree is valuable for many ornamental articles.

The colour of sycamore is generally of a brownish white; sometimes of a yellowish white, or nearly white in young wood, with a silky lustre. Its texture is nearly uniform, and the annual rings not very distinct. Its larger septa are small and close, and perhaps it might be more correctly described as having distinct smaller septa, and no larger septa. Its flowers are small, presenting a minute dappled appearance. The wood is sometimes beautifully curled. In large trees the wood is generally tainted and brittle. It is in general easy to work, being less hard than beech.

The cohesive force of a square inch varies from 5000 to 10,000 pounds; its modulus of elasticity is 1,036,000 pounds for a square inch. A cubic foot of sycamore weighs from 34 to 42 pounds when dry.

| | |
|---|---|
| Representing the strength of oak by 100, that of sycamore is ...... | 81 |
| stiffness of oak by 100, ...................... | 59 |
| toughness of oak by 100, ...................... | 111 |

Evelyn's Silva; Rondelet, l'Art de Batir.

## CLASS II.

382. The second class contains all woods that have no larger transverse septa. To this class many woods belong, and of various colours and qualities.

This class contains three divisions; the first and second formed on the same distinctions as the first and second in the first class (art. 374;) the third division includes all the woods of which the pores are filled with resinous matter.

### DIVISION I.

383. In the first division of the second class the annual ring is nearly compact towards one side, and porous towards the other side; and from this inequality the wood is very subject to warp in drying. I have only described four woods belonging to this division; those are the chesnut, the ash, the elm, and the false acacia.

### I. Chesnut.

384. The wood called chesnut is the produce of the *Fagus castanea* of botanists, commonly called the *sweet* or *Spanish* chesnut. This tree is a native of the warmer mountainous parts of Europe, and was once very common in this country. Fitz-Stephens, in a description of London in Henry II.'s time, states, that a noble forest of chesnuts grew on the north part of it; and many of the old buildings appear to have been built with this wood; indeed it appears to have been the chief timber used in earlier times.

It is one of the largest and most long-lived of European trees, sometimes enduring more than a thousand years. The mean size of its trunk, according to Hassenfratz, is about 44 feet in length and 37 inches in diameter; and it is of a rapid growth.

The chesnut contains only a very small proportion of sap-wood, and therefore the wood of young trees is found to be superior even to oak in durability. Marshall states, that hop-poles of this wood last longer than any other*; and in pales, stakes, and posts, it has been known to last from 20 to 30 years, which is longer than most woods last in such situations. Mr. Kent has observed a post of chesnut taken up sound after having stood above 40 years†; and Miller says it will endure longer than elm to convey water under ground. The roof of Westminster Hall‡, and that of King's College, Cambridge, may be cited as examples of its durability in a dry state; also the roof of the church of Notre-Dame at Paris. Rondelet however observes, that several old buildings near Paris, of which the timbers were supposed to be chesnut, were examined by Buffon and d'Aubenton, who found the pretended chesnut to be a variety of oak. And it is probable that a closer examination will prove the roof of Westminster Hall to be of oak.

Chesnut is useful for the same purposes as oak, when the timber is not from old trees; but the wood of old trees is unfit for any situation where an uncertain load is to be borne, as it is brittle; and, as Evelyn states, often makes a fair show outwardly

* Rural Economy of the Southern Counties, vol. i. p. 216.

† Trans. of the Society of Arts, vol. x. p. 30.

‡ Encyclopædia Britannica, Supplement, art. Dry Rot, p. 684.

when it is decayed and rotten within. According to Belidor, it soon rots when built in a wall, therefore the ends of joists of this wood should have a free space left round them.

The wood of the chesnut is nearly of the same colour as that of the oak. In old wood the sap-wood of chesnut is whiter and the heart-wood browner; but it is so much like oak that in old buildings they have been sometimes mistaken the one for the other. Sir H. Davy says, "they may be easily known by this circumstance, that the pores in the alburnum of the oak are much larger, and more thickly set, and are easily distinguished; whilst the pores in the chesnut require glasses to be seen distinctly*." Chesnut has no larger transverse septa, which is a more decided distinction, and renders it easy to know it from oak, whether the wood be old or not.

The wood is hard and compact; young wood is tough and flexible, old wood is brittle, and often shaky. It does not shrink and swell so much as other woods, and is easier to work than British oak.

The cohesive force of a square inch of chesnut varies from 9570 to 12,000 pounds, when dry. The weight of a cubic foot dry is from 43 to 54·8 pounds.

The properties as determined from a piece of young wood in a green state are as under. The cohesive force of a square inch of green chesnut is 8,100 pounds; the weight of the modulus of elasticity per square inch of ditto, is 924,750 pounds; the weight of a cubic foot of ditto, 54·68 pounds.

| | | |
|---|---|---|
| Representing the strength of dry oak by | 100, that of green chesnut is | 68 |
| stiffness of dry oak by | 100, .................. | 54 |
| toughness of dry oak by | 100, .................. | 85 |

Since the preceding part of this article was written and sent to the press, an opportunity has offered of making some experiments on dry chesnut; and as they strongly confirm a very old observation respecting it, I am glad of having the power of adding them, to render this article more complete.

The wood of the specimens submitted to experiment was from a tree of about thirty years growth, and 11 inches diameter; consequently it had been rapidly grown. Its specific gravity was 0·535.

The first trial was made with the supports 30 inches apart, but a small knot near the middle caused the specimen to break with a long splinter, consequently it was not a fair measure of its strength. The fracture took place so suddenly, and so unexpectedly, that I narrowly escaped an accident; as, unlike other woods, it gave no warning whatever. The second trial was made with the supports 24 inches apart, and may be considered a fair measure of the strength of chesnut; but though the bending

* Agricultural Chemistry, p. 222, 4to. edit.

was very considerable, the last measure taken being 2¼ inches, it broke as suddenly as the first specimen, and without any previous cracking or other signs of fracture. The result of these trials may be seen in the following table.

| | Length. | Area of section. | | |
|---|---|---|---|---|
| First specimen | 30 inches | 1 inch square | bent 0·5 inches with | 85 pounds. |
| Ditto | ditto | ditto | broke at a knot.... | 153 |
| Second specimen | 24 inches | ditto | bent 0·5 inches .... | 163 |
| Ditto | ditto | ditto | broke ............ | 296 |

According to the experiment on the second specimen, the cohesion of a square inch of Spanish chesnut is 10,656 pounds: and the modulus of elasticity for a square inch, according to the first experiment, is 1,147,500 pounds; according to the second experiment, 1,126,656 pounds.

It bends more than oak at the time of fracture, and therefore is tougher. Its toughness seems to permit it to yield insensibly till every particle exerts its utmost force, and then it gives way at once, more in the manner of metals than in that of woods. Its properties are compared with those of oak in the table No. 20, at the end of the volume.

Rees's Cyclopædia; Miller's Gardener's Dictionary, art. Castanea; Evelyn's Silva; Rondelet, L'Art de Batir; Belidor, Science des Ingenieurs.

### 2. Ash.

385. The common ash (the *Fraxinus excelsior* of botanists) is a native of Europe and the north of Asia, and is the most valuable of the genus. There are other species both in America and other places, but I do not know any thing worthy of notice respecting their wood.

The ash is a very rapid growing tree, and, like the chesnut, the young wood is much more valuable than that of old trees. No timber differs more from a difference of soil and situation than the ash. The mean size of the trunk is, according to Hassenfratz, 38 feet in length and 23 inches in diameter; but sometimes this tree attains an immense size.

Ash soon rots when exposed to either damp or alternate dryness and moisture, but is tolerably durable in a dry situation. Evelyn says, the best season for felling ash is from November to February, and that when felled in full sap it is very subject to the worm. The pores of ash cut in the spring are of a reddish colour, and such wood is much benefited by water-seasoning.

Ash is superior to any other British timber for its toughness and elasticity; and in consequence of these properties, it is useful wherever sudden shocks are to be sustained; as in various parts of machines, wheel carriages, implements of husbandry, ship blocks, tools, and the like; being equally as useful in the arts of war as in those of peace, in ancient as well as in modern times:

> "From Pelion's cloudy top, an ash entire
> Old Chiron fell'd, and shap'd it for his sire." Pope's Homer.

It is too flexible for the timbers of buildings, and not sufficiently durable.

The colour of the wood of old trees is oak brown, with a more veined appearance, the veins darker than in oak, sometimes the wood is very beautifully figured. The wood of young trees is brownish white with a shade of green.

Its texture is alternately compact and porous, the compact side of the annual ring being the darker coloured, which renders the annual rings very distinct. It has no larger septa, and consequently it has no flowers.

It has neither taste nor smell, and is difficult to work, except the wood of old trees, which is of a more brittle nature.

The cohesive force of a square inch varies from 6300 to 17,000 pounds; and the weight of its modulus of elasticity is about 1,525,500 pounds per square inch. The weight of a cubic foot dry varies from 34 to 52 pounds; when the weight of a cubic foot is lower than 45 pounds, the wood is that of an old tree, and will be found deficient both in strength and toughness.

| | |
|---|---|
| Representing the strength of oak by 100, that of ash is | 119 |
| stiffness of oak by 100, | 89 |
| toughness of oak by 100, | 160 |

It exceeds oak both in strength and toughness, and in young wood the difference is still more considerable.

Miller's Gardener's Dictionary; Rees's Cyclopædia; Evelyn's Silva; Ellis's Timber Tree Improved; and Rondelet, L'Art de Batir.

### 3. Elm.

386. Of the elm tree (the *Ulmus* of botanists) there are five species now common in Britain; viz. the common rough-leaved elm, the cork-barked elm, the broad-leaved elm or wych hazel, the smooth-leaved or wych elm, and the Dutch elm.

The common rough-leaved elm (*Ulmus campestris*) is common in scattered woods and hedges in the southern parts of England; it is a harder and more durable wood than the other species; it resists moisture well, and is therefore preferred for coffins.

The cork-barked elm (*Ulmus suberosa*) is very common in Sussex, the wood is of an inferior kind.

The broad-leaved elm or wych hazel (*Ulmus montana*) appears to be the most common species throughout Europe; it is frequent in the woods and hedges of England, particularly in the northern counties. Sir J. E. Smith says, "the wood fetches about half the price of our Norfolk campestris."

The smooth-leaved or wych elm (*Ulmus glabra*) common in Herefordshire, Essex, and the north and north-east counties of England, grows to a large size, and is much esteemed; the wood is stated to be preferred for naves of wheels.

The Dutch elm (*Ulmus major*) is a native of Holland, its wood is very inferior to the other species; indeed Miller says it is good for nothing.

The wych elm is the largest tree, and the Dutch elm the smallest. Hassenfratz states the mean size of the trunk of the elm tree to be 44 feet in length and 32 inches in diameter. The trunk of the common rough-leaved elm is often rugged and crooked, and the tree is of slow growth. Marshall says the Vale of Gloucester produces some very fine elms, but has not described the species.

Elm has always been much esteemed for its durability in situations where it is constantly wet; and it is also said to be very durable in a perfectly dry state, but not when exposed to the weather. The piles upon which London Bridge stands are chiefly of elm, and have remained six centuries without material decay*; and several other instances of its durability in water have been noticed.

Elm is not useful for the general purposes of building, but from its durability in water it makes excellent piles and planking for wet foundations. It is also used for water-works, such as pipes, pumps, and the like, and it is much used for coffins. The naves of wheels, the shells of blocks for tackle, the keels of ships, and sometimes the gunwales are made of elm.

The colour of the heart-wood of elm is generally darker than that of oak, and of a redder brown. The sap-wood is of a yellowish or brownish white, with pores inclined to red. Elm is in general porous, and cross-grained; sometimes very coarse grained, and has no larger septa. It has a peculiar odour. It twists and warps much in drying, and shrinks very much both in length and breadth. It is difficult to work, but is not liable to split, and bears the driving of bolts and nails better than any other timber. The timber of the English elm is generally esteemed the best, that of the wych elm is equally as good, but the Dutch elm is very inferior.

The cohesive force of a square inch of elm varies from 6070 to 13,200 pounds; and the weight of its modulus of elasticity for a square inch is about 1,343,000 pounds. The weight of a cubic foot dry is from 34 to 47 pounds; seasoned, from 36 to 50 pounds.

* Hutton's Tracts, vol. i. p. 119.

Representing the mean strength of oak by 100, that of elm is ...... 82
stiffness of oak by 100, .................. 78
toughness of oak by 100, .................. 86

According to the experiments of Mr. Couch, elm shrinks one-forty-fourth part of its width in seasoning.

Rees's Cyclopædia, art. Ulmus; Miller's Gardener's Dictionary; Evelyn's Silva; Rondelet, L'Art de Batir; Barlow's Essay on the Strength of Timber; Winch on the Geography of Plants; and Annals of Philosophy for 1818.

### 4. COMMON ACACIA.

387. The common acacia or locust tree (*Robinia pseudo-acacia* of botanists) is a native of the mountains of America from Canada to Carolina. It is a beautiful tree, attains a considerable size, and is of very quick growth. According to Hassenfratz, the mean size of its trunk is 32 feet in length and 23 inches diameter.

The wood is much valued for its durability; some of the houses built by the first settlers in New England of this wood still continue firm and sound; and in posts, stakes, and pales, it is found to be one of the most durable kinds. It is adapted for any purpose to which oak is applied; it makes excellent tree-nails for ships, and is valuable for fencing. There are several other species, but I have only specimens of the kind now described.

The colour of the wood of the acacia is of a greenish yellow, with a slight tinge of red in the pores. Its structure is alternately, nearly compact, and very porous, which marks distinctly the annual rings. It has no larger septa, and therefore no flowers. It has no sensible taste or odour in a dry state. It will require about the same degree of labour to work it as ash does.

The cohesive force of a square inch varies from 10,000 to 13,000 pounds; and the weight of a cubic foot seasoned is from 49 to 56 pounds. Its other properties, determined from young wood in an unseasoned state, are as under:

Weight of the modulus of elasticity for a square inch 1,687,500 pounds.

Representing the mean strength of oak by 100, that of unseasoned acacia is 95
stiffness of oak by 100, ........................ 98
toughness of oak by 100, ........................ 92

Hence in a dry state it will be superior to oak in these properties.

Rees's Cyclopædia, art. Robinia; Evelyn's Silva, Hunter's edit.; and Rondelet, L'Art de Batir.

## DIVISION II.

388. In the second division of the second class the wood is uniformly porous; the distinction of the rings is chiefly owing to a difference between the colours of the sides of each ring. To this uniformity of texture may be referred the superiority of the woods in this division in retaining their original form; or, in other words, it is the reason they stand so well in work. The woods of this division are very numerous, but many of them have little durability; only four are here described, those are, mahogany, walnut, teak, and poplar.

### 1. MAHOGANY.

389. Mahogany is the produce of the tree called by botanists *Swietenia mahogoni*. It is a native of the West Indies, and the country round the Bay of Honduras in America.

There are other two species of swietenia besides the mahogany tree, which are natives of the East Indies. The one a large tree, of which the wood is of a dull red colour, and remarkably hard and heavy. The other is only a middle sized tree, with wood of a deep yellow colour, close grain, heavy, and durable, much resembling that of the box tree; but neither of these species are in use in this country.

The mahogany tree is stated to be of very rapid growth, and makes a very fine appearance. Its trunk often exceeds 40 feet in length, and 6 feet in diameter. The Honduras mahogany is cut down at two periods in the year; that is, at Christmas and in the autumn. The trees are cut off at about 12 feet from the ground; the workmen having a stage to work upon. The trunk furnishes wood of the largest dimensions, but for ornamental purposes the branches are preferable; the grain in them being closer and the veins more variegated. Mahogany was first brought to London in the year 1724.

In a dry state mahogany is very durable, and not subject to worms. It does not last long when exposed to the weather. It is a kind of wood that would make excellent timbers for floors, roofs, &c. but on account of its price its use is chiefly confined to furniture and doors for rooms; for which purposes it is the best material in use. It is sometimes used for some parts of window frames, and for sashes; but from its not standing the weather well, it is not so fit for these purposes. It has also been extensively used in the framing of machinery for cotton mills, &c.

The colour of mahogany is a red brown, of different shades, and various degrees of brightness; sometimes yellowish brown; often very much veined and mottled, with darker shades of the same colour.

The texture is uniform, and the annual rings are not very distinct. It has no larger septa, but the smaller septa are often very visible, with pores between them; these pores are often filled with a white substance in the Jamaica wood, but generally empty in the Honduras kind. It has neither taste nor smell, shrinks very little, and warps or twists less than any other kind of wood.

The variety called Spanish mahogany is imported from Cuba, Jamaica, Hispaniola, and some other of the West Indian islands, and in smaller logs than the Honduras. The size of the logs is in general about from 20 to 26 inches square, and about 10 feet in length. The Spanish mahogany is close grained and hard, generally of a darker colour than Honduras; free from black specks, and sometimes strongly figured; and its pores appear as if chalk had been rubbed into them.

The Honduras mahogany is imported in logs of a larger size, that is, from 2 to 4 feet square, and 12 or 14 feet in length; sometimes planks have been got 6 or 7 feet wide. The grain of the Honduras kind is generally very open, and often irregular, with black or grey spots. The veins and figures are frequently very fine and showy; the best kind is that which is most free from grey specks, and of a fine golden colour. It holds with glue better than any other wood.

The cohesive force of a square inch of Spanish mahogany is 7560 pounds, and of Honduras mahogany is 11,475 pounds.

The weight of the modulus of elasticity of mahogany is 1,255,500 pounds, for a square inch for Spanish; and 1,593,000 for Honduras. The weight of a cubic foot of mahogany is from 35 to 53 pounds.

| | | | |
|---|---|---|---|
| Representing the strength of oak by | 100, that of Span. mahog. is | 67, of Hond. is | 96 |
| stiffness of oak by | 100, .................... | 73, .......... | 93 |
| toughness of oak by | 100, .................... | 61, .......... | 99 |

## 2. WALNUT.

390. The common walnut tree (*Juglans regia*) is a native of Persia, and the northern parts of China. It was formerly much propagated in England for its wood, which was much esteemed before mahogany was introduced. The wood is very beautiful, and is still much prized by people of taste, who consider its colour to be far superior to the red brown of mahogany.

Walnut, on account of its scarcity, is scarcely ever used for the purposes of building; indeed it is of too flexible a nature for beams, though it appears to have been used for that purpose by the ancients. Pliny observes, that it has the good property of giving warning by cracking before it breaks; hence when the baths of Antendros failed, the bathers were alarmed in time to save themselves. The wood is durable, and not liable

to be destroyed by worms; and it is much used for gun-stocks, and sometimes for furniture.

The hickery or white walnut (*Juglans alba*) is a native of North America. It is a large tree, the trunk sometimes exceeding three feet in diameter. The wood of young trees is extremely tough and flexible, making excellent hand-spikes.

The black Virginia walnut (*Juglans nigra*) is also a native of America, and is found from Pennsylvania to Florida. It is a large tree, and for furniture the wood is the most valuable of the walnut-tree kind. It is of a fine grain, and beautifully veined, receiving an excellent polish. It is also durable, and not affected by worms.

The heart-wood of walnut tree is of a grayish brown, with blackish brown pores, often much veined, with darker shades of the same colour; the sap-wood is grayish white. The colours are much brightened, and the veins rendered more distinct by oiling. Its texture is not so uniform as that of mahogany, the pores being somewhat more thickly set on one side of the annual ring. It has no larger septa nor flowers. It has a slightly bitter taste when green, and a perceptible odour. It does not work so easily as mahogany, but may in general be brought to a smoother surface. It shrinks very little.

The cohesive force of a square inch of walnut varies from 5360 to 8130 pounds; its modulus of elasticity for a square inch is 837,000 pounds, in a green state; the weight of a cubic foot varies from 40 to 48 pounds, in a dry state.

| | |
|---|---|
| Representing the strength of oak by 100, that of common walnut is | 74 |
| stiffness of oak by 100, ...................... | 49 |
| toughness of oak by 100, ...................... | 111 |

These properties were ascertained from a green specimen; the strength and stiffness would be greater in a dry state.

Miller's Gardener's Dictionary; Rondelet, l'Art de Batir; and Rees's Cyclopædia.

### 3. Teak Wood, or Indian Oak.

391. Teak wood is the produce of the *Tectona grandis* of botanists, and is a native of the mountainous parts of the Malabar and Coromandel coasts, as well as of Java, Ceylon, and other parts of the East Indies.

The teak tree is of rapid growth, and the trunk grows erect, to a vast height, with copious spreading branches.

The wood of the teak tree is by far the most useful timber in India; it is light, easily worked, and, though porous, it is strong and durable; it requires little seasoning, and shrinks very little; it is rather of an oily nature, therefore does not injure iron;

and is the best wood in that country for ship-timber, house carpentry, or any other work where strong and durable wood is required.

Malabar teak is esteemed superior to any other in India, and is extensively used for ship-building at Bombay. It grows in the teak forests, along the western side of the Ghaut Mountains, and the contiguous ridges, where the numerous streams afford water-carriage for the timber. There is a variety, says Dr. Roxburgh, grows on the banks of the Godovery, in Hindostan, of which the wood is beautifully veined, closer grained, and heavier than that of the common teak tree, which is well adapted for furniture.

The cohesive force of teak wood varies from 13,000 to 15,000 pounds per square inch; the weight of its modulus of elasticity is 2,167,000 pounds per square inch, according to Mr. Barlow's experiments; and the weight of a cubic foot seasoned varies from 41 to 53 pounds.

| | | |
|---|---|---|
| Representing the strength of oak by | 100, that of teak will be ...... | 109 |
| stiffness of oak by | 100, ........................ | 126 |
| toughness of oak by | 100, ........................ | 94 |

From which it appears, that it is much superior to oak in these properties, except in toughness; but it is to be remembered, that these proportions are drawn from two or three experiments on teak, and most probably these were tried on very select specimens; whereas those for oak are from a mean specimen, selected from pieces of oak of various qualities.

Transactions of the Society of Arts, vol. xxx.; Rees's Cyclopædia; Supplement to the Encyclopædia Britannica; Barlow's Essay on the Strength of Timber; and Quarterly Review, vol. x.

## 4. POPLAR.

392. Of the poplar tree (the *Populus* of botanists) there are five species common in England. The common white poplar, the black poplar, the aspen or trembling poplar, the abele or great white poplar, and the Lombardy poplar.

The wood of the aspen lasts long exposed to the weather, and most of the poplars prove very durable in a dry state; agreeable to the woodman's adage,

> "Cover me well to keep me dry,
> And *heart* of oak I do defy." CRAGG.

The wood of most of the species makes very good flooring for bed-rooms, and places where there is not much wear, and it has the advantage of not catching fire readily; or, as Evelyn has it, "the poplar burns untowardly, and rather moulders away than maintains

any solid heat." As Vitruvius has observed of the poplars, they are woods sufficiently strong for light purposes, being soft, white, and easy to work, and well adapted for carving; but none of the species are fit for large timbers.

There is not much difference in the wood of these species. The colour is of a yellowish or brownish white; one side of the annual rings being a little darker than the other, which renders the growth of each year visible. They are of an uniform texture, and are without the larger septa. The Lombardy, the black, and the common white poplar are the most esteemed. The Lombardy poplar is sometimes recommended for cheese-rooms and farm-houses in general, because neither mice nor mites will attack it.

The cohesive force of a square inch of common white poplar is from 4596 to 6641 pounds, and the others will not differ much from it; the weight of the modulus of elasticity for a square inch is, for abele 1,134,000 pounds, and for Lombardy poplar 763,000 pounds; the weight of a cubic foot dry is, for abele 32 pounds, for common white poplar 33 pounds, for Lombardy poplar 24 pounds, for aspen and for black poplar 26 pounds.

| | | | |
|---|---|---|---|
| Representing the strength of oak by | 100, | that of abele is 86, | that of Lom. pop. is 50 |
| stiffness of oak by | 100, | ............. 66, | .................. 44 |
| toughness of oak by | 100, | .............112, | .................. 57 |

Rees's Cyclopædia; Miller's Gardener's Dictionary; Vitruvius, lib. ii. cap. ix.; and Evelyn's Silva.

## DIVISION III.

393. In the third division of the second class the woods are distinguished by the pores containing resinous matter. Some of the most useful and the most durable kinds of wood belong to this division. The cedars and the different species of pine belong to this division.

### 1. Cedar of Libanus, or the Great Cedar.

394. The cedar of Libanus, or *Pinus cedrus* of botanists, is a cone-bearing tree, and an evergreen; it is a native of Mount Libanus, whence it has its name. The finest cedars in the time of Vitruvius grew in Candia and Afriea; and there were also some grown in Syria, but we do not know of what species.

It grows to a considerable size; the mean size of the trunk, according to Hassenfratz, is about 39 inches in diameter, and 50 feet in length. Several very fine cedars have

been produced in this country. The tree which furnished the specimens on which my experiments were made was 34 inches in diameter; it was grown at Ditton Park, near Windsor.

The wood is said to be very durable. It is stated by Pliny, that in the Temple of Apollo, at Uttica, cedar was found of nearly 1200 years old. According to Vitruvius, the statue of Diana, in the famous Temple at Ephesus, was of cedar, as well as the timber-work of the floor and ceiling of that edifice; and he further states, that the timber-work of the most celebrated temples of antiquity was in general executed in cedar, on account of its extreme durability. The cedar used for statues was most probably the oxycedrus (see art. 403;) but though Vitruvius describes the cedar as having a leaf like cypress, that used for beams, floors, and other parts of the temples, was most likely to be the great cedar, as it does not appear that the other kinds are large enough for such purposes. Cedar of Libanus was used by Solomon in the construction of the Temple at Jerusalem.

It has no larger perceptible transverse septa, but when it is planed where it has been cut across the annual rings, the smaller septa present a very minute and beautiful dappled appearance. The general colour of cedar is a rich light yellowish brown; the annual rings distinct, each ring consisting of two parts, the one part harder, darker coloured, and more compact than the other.

It is a resinous wood, and has a peculiar and powerful odour, with a slightly bitter taste, and is not subject to the worm. It is straight grained, and easily worked, but readily splits.

The cohesive force of a square inch of cedar is 7400 pounds; the weight of its modulus of elasticity for a square inch is 486,000 pounds, according to my experiments; and the weight of a cubic foot seasoned is from 30·5 to 38 pounds.

| | |
|---|---|
| Representing the strength of oak by 100, that of cedar is ........ | 62 |
| stiffness of oak by 100, ........................ | 28 |
| toughness of oak by 100, ........................ | 137 |

From these proportions it appears, that it exceeds the oak in toughness, but is vastly inferior in stiffness and strength.

Evelyn's Silva; Miller's Gardener's Dictionary; Rondelet, L'Art de Batir, tome iv.; 1 Kings v. and vi.; and Perrault's Vitruvius, liv. ii. chap. ix.

### 2. RED OR YELLOW FIR.

395. Red or yellow fir is the produce of the Scotch fir tree (the ***Pinus sylvestris*** of botanists;) it is a native of the hills of Scotland, and other northern parts of Europe,

and common in Russia, Denmark, Norway, Lapland, and Sweden. The great forests of Norway and Sweden consist almost entirely of Scotch fir and spruce fir. The Scotch fir is exported from thence in logs and deals, under the name of red-wood. Norway exports no trees above 18 inches diameter, consequently there is much sap-wood; but the heart-wood is both stronger and more durable than that of larger trees from other situations. Riga exports a considerable quantity under the name of masts and spars: those pieces from 18 to 25 inches diameter are called *masts*, and are usually 70 or 80 feet in length; those of less than 18 inches diameter are called *spars*. According to Mr. Coxe, the greater part of the Riga timber is grown in the districts near the Dneiper. Yellow deals and planks are imported from Stockholm, Gefle, Frederickshall, Christiana, and various other ports of Norway, Sweden, Prussia, and Russia.

The Scotch fir is often grown in English plantations, but the wood is seldom of much value, as it succeeds only upon dry gravelly ground; and it appears to me to be an inferior variety of the pinus sylvestris that is usually planted; if not a different species from that which produces the Riga timber. In the mountainous tract through which the river Dee traverses, in Aberdeenshire, there is a fine forest of natural grown wood; some of the trees exceed 3 feet in diameter and 90 feet in height. The wood is of a very good quality, but not equal to the best foreign kinds.

Tar, pitch, and turpentine, are obtained from the Scotch fir; and the tree is not injured by extracting these products, when it has acquired a certain age; indeed some suppose the wood to be improved by it.

It is the most durable of the pine species; and it was the opinion of the celebrated Mr. Brindley, the conductor of the Grand Trunk Canal, and an opinion founded on observation, "that red Riga deal, or pine wood, would endure as long as oak in all situations*." Similar observations have been made by Mr. Semple†.

An instance of the durability of fir is given by Duhamel, who states, that the piles of the foundations of an old church, which had existed many centuries, were found to be perfectly sound in the centre, which still had the colour and odour of resin, but the outside was a little decayed. And an instance of the durability of natural grown Scotch fir is given by Dr. Smith, who states, that he had seen some of it, which, after it had been 300 years in the roof of an old castle, was as fresh and full of sap as new imported from Memel;" and "that part of it was actually wrought up into new furniture‡." And here it may be observed, that foreign timber has an advantage that is too seldom allowed to that which is home grown; for it is always seasoned in some degree before it arrives in this country, therefore cannot be employed in so unseasoned a state as British timber is generally employed.

* Darwin's Phytologia, p. 521.

† Treatise on Building in Water, p. 86.

‡ Dr. Smith, quoted by Pontey, Forest Pruner, p. 71.

Its lightness and stiffness render it superior to any other material for beams, girders, joists, rafters, and framing in general. It is also much used for masts and other parts of vessels. For joiners' work it is also much used, both for external and internal work, as it is more easily wrought, stands better, is nearly, if not quite as durable, and is much cheaper than oak.

The colour of the wood of the different varieties of Scotch fir differs considerably; it is generally of a reddish yellow, or a honey yellow, of various degrees of brightness. It consists in the section of alternate hard and soft circles; the one part of each annual ring being soft and light coloured, the other harder and dark coloured. It has no larger transverse septa, and it has a strong resinous odour and taste. It works easily when it does not abound in resin; and the foreign wood shrinks about one-thirtieth part of its width in seasoning from the log.

In the best timber the annual rings are thin, not exceeding one-tenth of an inch in thickness; the dark parts of the rings of a bright and reddish colour; the wood hard and dry to the feel, neither leaving a woolly surface after the saw, nor filling its teeth with resin. The best Norway is the finest of this kind, and the best Riga and Memel are not much inferior.

The inferior kinds have thick annual rings; in some kinds the dark parts of the rings are of a honey yellow, the wood heavy, and filled with soft resinous matter, feels clammy, and chokes the saw. Timber of this kind is not durable, nor fit for bearing strains. Mar Forest timber is often of this kind. In other inferior kinds the wood is spongy, contains less resinous matter, and presents a woolly surface after the saw. Swedish timber is often of this kind, and is then inferior in strength and stiffness.

The cohesive force of a sq. in. of foreign timber varies from 7000 to 14000 pounds.
of Mar Forest ............ 7000 to 10000
of English growth ........ 5000 to 7000

The weight of a cubic foot of foreign fir seasoned varies from 29 to 40
of English growth, seasoned...... 28 to 33
of Mar Forest .................. 38

The mean weight of the modulus of elasticity for a square inch
of the foreign varieties of Scotch fir of a good quality is 1,687,000 pounds.
of Mar Forest ........................................ 845,000
of English ........................................ 951,000

The mean strength, stiffness, and toughness, of oak, being each represented by 100, those of the different varieties of Scotch fir will be represented by the numbers below:

Strength of foreign timber 80, of Mar Forest ditto 61, of English grown ditto 60
Stiffness .............. 114,................. 49,..................... 55
Toughness ............ 56,................. 76,..................... 65

Mr. John White favoured me with a specimen of Norway yellow fir much superior to any of the fir kind that has been experimented upon; its strength was to that of oak as 120 to 100; its weight per cubic foot 39 pounds.

The wood from cold climates appears to be always much harder than that which is the product of warmer countries; for from the under side of crooked pine trees the Laplanders procure what they term *kior*, which is always as hard as box wood: this they use for the bottoms of their sledges, and for the outer part of their bows. The Norway timber is also harder than that of Riga, &c.

Rees's Cyclopædia, art. Pinus; Barlow's Essay on the Strength of Timber; Von Buch's Travels in Norway; Linnæus's Tour in Lapland, vol. i. and ii.; and Coxe's Travels in Russia.

### 3. White Fir or Deal.

396. White fir is the produce of different species of spruce fir; that from the north of Europe is produced by the Norway spruce (*Pinus abies* of botanists;) but that from America is produced either by the white spruce (*Pinus alba,*) or black spruce (*Pinus nigra.*) White fir is imported in deals or planks.

The Norway spruce (*Pinus abies*) is a native of mountains in various parts of Europe and the north of Asia. The forests of Norway afford it abundantly. A considerable quantity is imported from Christiana in deals and planks, which are esteemed the best white deals of any; not so much, Von Buch says, from the superior quality of the tree, as the regular thickness of the deals. The trees are usually cut into three lengths, generally of about twelve feet each, and are afterwards cut into deals and planks by saw mills, each length yielding three deals or planks. A tree requires 70 or 80 years' growth before it arrives at perfection. White deals are also imported from Frederickstadt, Drontheim, and other ports in Norway; and from Gottenburg, Riga, and other of the Baltic ports. At Christiana, Mr. Coxe states, that each saw mill is restricted from cutting more than a certain quantity of deals: at that port there are 136 saw mills, and the quantity permitted to be cut amounts to twenty million standard deals, 12 feet long and $1\frac{1}{4}$ inch thick.

It is from the Norway spruce that the Burgundy pitch is obtained. It thrives very well in Britain, and produces very good timber, little inferior to the foreign; it is somewhat softer, and the knots are extremely hard, which renders it difficult to work. White deal is very durable in a dry state, and is much used for internal joiners' work, and for furniture. It unites well with glue.

The American white spruce fir (*Pinus alba,*) in Canada called *epinette*, or rather

*sapinette blanche*, is a native of high mountainous tracts in the colder parts of North America. The wood is not so resinous as that of the Norway spruce, and it is tougher, less heavy, and generally more liable to twist in drying. It is imported in deals and planks.

The American black spruce fir (*Pinus nigra*) is a native of the high mountainous tracts from the northern part of Canada to Carolina. The black and white spruce are so named from the colour of the bark, the wood of both kinds being of the same colour. The black spruce is said to produce the best wood: I have not, however, been able to procure a specimen that was known to be from that tree.

The colour of spruce fir, or white deal, is yellowish or brownish white; the hard part of the annual ring a darker shade of the same colour; often has a silky lustre, especially in the American and British grown kinds. Each annual ring consists of two parts, the one hard, the other softer. The knots are generally very hard, and the clear and straight grained kinds are often tough, but not very difficult to work, and stand extremely well when properly seasoned.

The cohesive force of a square inch of Christiana deal is from 8000 to 12000 pounds.
of American white spruce ............ 8000 to 10000
of British grown Norway spruce is about 8000

The modulus of elasticity is 1,500,000 pounds for a square inch, taking the mean of the three kinds.

A cubic foot of Christiana deal weighs from ...... 28 to 32 pounds when dry.
of American white spruce................ 29
of Norway spruce (British grown) ......... 34

Representing the strength, stiffness, and hardness of oak, each by 100,

| | Christiana deal. | American white spruce. | British grown Norway spruce. |
|---|---|---|---|
| The strength will be .... | 104 | 86 | 70 |
| The stiffness .......... | 104 | 72 | 81 |
| The toughness ......... | 104 | 102 | 60 |

The shrinkage of white deal is about one-seventieth part in becoming perfectly dry, according to my observations; the deals being in the state they are usually purchased at the timber-yards when first measured. What are termed dry deals will shrink about one-ninetieth part.

Von Buch's Travels in Norway; Rees's Cyclopædia, art. Pinus; Evelyn's Silva; and Coxe's Travels in Norway.

4. AMERICAN PINES; 5. PITCH PINE; 6. SILVER FIR; and, 7. PINASTER.

397. The Weymouth pine or white pine (*Pinus strobus*) is a native of North America, and is imported in large logs, often more than 2 feet square and 30 feet in length. It is one of the largest and most useful of the American pines, and makes excellent masts. The wood is light and soft, but is said to stand the weather tolerably well.

In joiners' work the wood is much used for mouldings, and other work where clean straight grained wood is desirable; but it is not durable, nor fit for large timbers, being very liable to take the dry rot. It has a peculiar odour.

The colour of the wood is a brownish yellow, the texture is more nearly uniform than that of any other of the pine species, and the annual rings not very distinct. It stands very well when seasoned, and is a very good kind of wood for moulds for casting from, and for some kinds of furniture; but its softness renders it unfit for many purposes. Its strength, &c. are given in a table in the following page.

398. Yellow pine (*Pinus variabilis*) is a native of the pine forests from New England to Georgia, and the wood is much used for many of the carpenter's purposes, and for ship-building. It is also imported into Britain; but I have not been able to procure specimens that were known to be from this tree.

399. The pitch pine (*Pinus resinosa*) is a native of Canada, and is remarkable for the abundance and fragrance of its resin. It is a very heavy wood, and not very durable; it is also brittle when very dry. It is of a redder colour than the Scotch pine, feels sticky, and is difficult to plane. Its other properties are given in the table in the following page.

400. The silver fir (*Pinus picea*) is a native of the mountains of Siberia, Germany, and Switzerland, and is common in British plantations. It is a large tree, and produces the Strasburg turpentine of commerce. The wood is of a good quality, and much used on the continent both for carpentry and ship-building. The harder fibres are of a yellow colour, compact, and resinous; the softer nearly white. Like the other kinds of fir, it is light and stiff, and does not bend much under a considerable load; consequently floors constructed of it remain permanently level. It is subject to the worm. Wiebeking says, it lasts longer in the air than in water, and it is therefore more fit for the upper parts of bridges than for piles and piers.

401. The cluster pine (*Pinus pinaster*) is a native of the rocky mountainous parts of Europe, and is sometimes cultivated in British plantations. It is a larger tree than the Scotch pine, and produces both pitch and turpentine; and its wood is not of so red a colour.

Wiebeking says, the wood of the pinastér is more durable in water than in air, that it is of a finer grain than either the pine or silver fir, and contains less resin than either.

*Table of Properties of the preceding Species.*

| Kind. | Weight of a cubic foot. | Weight of modulus of elasticity for a square inch. | Cohesive force of a square inch. | Comparative stiffness. | Comparative strength. | Comparative toughness. |
|---|---|---|---|---|---|---|
| | pounds. | pounds. | pounds. | | | |
| Weymouth pine | 28¾ | 1,633,500 | 11,835 | 95 | 99 | 103 |
| Yellow pine.... | 28 | | | | | |
| Pitch pine..... | 41 | 1,252,200 | 9,796 | 73 | 82 | 92 |
| Silver fir ...... | 25½ | | | | | |
| Pinaster....... | 25½ | | | | | |

In the fifth, sixth, and seventh columns, the stiffness, strength, and toughness of oak are each supposed to be represented by 100.

Rees's Cyclopædia, art. Pinus; Wiebeking on Bridges; and Barlow's Essay on the Strength of Timber.

### 8. Larch.

402. Of the larch tree there are three species; one European, and two American. The European larch tree (***Pinus larix***) is a native of the Alps of Switzerland, Italy, Germany, and Siberia. The variety from the Italian Alps is the most esteemed, and has been lately introduced to a considerable extent in the plantations of Britain. The present Duke of Atholl has been one of the most arduous in promoting this desirable object. It is a straight and lofty tree of rapid growth. A tree of 79 years' growth was cut at Blair Atholl in 1817, which contained 252 cubic feet of timber, and one of 80 years' growth at Dunkeld measured 300 cubic feet*, and a tree of 54 years' growth in Derbyshire contained 83½ cubic feet†. According to Hassenfratz, the mean size of the trunk is 45 feet in length and 33 inches in diameter.

It is extremely durable in all situations, failing only where any other kind would fail; for this valuable property it has been celebrated from the time of Vitruvius, who regrets that it could not be easily transported to Rome, where such a wood would have been so valuable. It appears, however, that this was sometimes done; for we are told that Tiberius caused the Naumachiarian Bridge, constructed by Augustus, and afterwards burnt, to be rebuilt of larch planks procured from Rhætia. Among these was a trunk

* Philosophical Magazine, vol. liii. p. 424. † Farey's Derbyshire Report, vol. ii. p. 252.

120 feet in length, which excited the admiration of all Rome*. The celebrated Scamozzi also extols the larch for every purpose of building; and it has not been found less valuable when grown in proper soils and situations in Britain.

In posts, and other situations where it is exposed to damp and the weather, it is found to be very durable. The Duke of Atholl has known it to last from 20 to 34 years in such situations, particularly the knotty top-wood.

In countries where larch abounds it is often used to cover buildings, which when first done are the natural colour of the wood, but in two or three years they become covered with resin, and as black as charcoal; the resin forms a kind of impenetrable varnish, which effectually resists the weather. Larch is not attacked by worms, and does not inflame readily.

The larch, says Wiebeking, is preferable to the pine, the pinaster, or the fir, for the construction of the arches of wooden bridges; and Mr. Coxe states, that the borderers on the Lake of Geneva prefer it for building their vessels: indeed the larch is useful for every purpose of building, whether external or internal; it makes excellent ship-timber, masts, boats, posts, rails, and furniture. In some parts of Kamtschatka it arrives at a considerable size, and is there used for ships, and lasts extremely well†. It is peculiarly adapted for flooring boards in situations where there is much wear, and for staircases; in the latter, its fine colour when rubbed with oil is much preferable to that of the black oaken staircases to be seen in some old mansions. It is well adapted for doors, shutters, and the like; and from the beautiful colour of its wood when varnished, painting is not necessary.

The wood of the American black larch (*Pinus pendula*) is said to be equal to that of the European larch; and that of the American red larch (*Pinus microcarpa*) is also of a very good quality; but they do not produce turpentine as the European kind.

Mr. Chapman states, that the wood of the larch tree is much improved in hardness by barking the trees in the spring, and felling them late in the autumn; and as a want of stiffness is one of the most striking defects of larch for the carpenter's purposes, such as joists and beams, it would be desirable that further trials should be made; as from the form of the tree, barking would be easily accomplished, as far as would be necessary.

The wood of the European larch is generally of a honey-yellow colour, the hard part of the annual rings of a redder cast; sometimes it is brownish white. In common with the other species of pine, each annual ring consists of a hard and soft part. It generally has a silky lustre, and its colour is browner than that of the Scotch pine, and it is much tougher. It is more difficult to work than Riga or Memel timber; but the surface is better when once it is obtained. It bears driving bolts and nails better than any other

* Beckmann's History of Inventions, vol. ii. p. 299.

† Langsdorff's Travels, vol. ii. p. 267.

kind of the resinous woods. When it has become perfectly dry it stands well, but warps much in seasoning.

The cohesive force of a square inch is from 6000 to 13,000 pounds; the modulus of elasticity for a square inch is 1,363,500 pounds; and the weight of a cubic foot of larch varies from 29 to 40 pounds when dry.

Representing the mean strength of oak by 100, that of larch is .... 103
stiffness of oak by 100, .................. 79
toughness of oak by 100, .................. 134

Of the larch wood there are two very distinct kinds, differing much both in colour and quality; the one being of a redder colour, harder, of a straighter grain, and more free from knots than the other, which is of a white colour and coarse grain. The white kind is the most common. I have made experiments on both kinds, from the Duke of Atholl's woods, in Scotland. It certainly would be desirable that trees producing woods so different in quality should be carefully examined by a scientific botanist.

Vitruvius, book ii. chap. ix.; Rees's Cyclopædia, art. Pinus; Wiebeking on Bridges; Coxe's Travels in Switzerland, vol. ii. p. 103; and Chapman on Preservation of Timber.

## 9. CEDAR.

403. Of the cedar tree (the *Juniperus* of botanists) there are several species that produce valuable wood. There are also several other kinds of timber that are often called cedar. Thus, a species of cypress is called white cedar in America; and the cedar used by the Japanese for building bridges, ships, houses, &c. is also a kind of cypress, which Thunberg describes as a beautiful wood, that lasts long without decay.

The *Juniperus oxycedrus* is a native of Spain, the south of France, and the Levant; it is usually called the brown-berried cedar. The wood of this species is supposed to have been the famous cedar of the ancients, so much celebrated for its durability, of which some of their first statues were made, before the use of marble in that branch of art was known.

The Bermudian cedar (*Juniperus Bermudiana*) a native of Bermuda and the Bahama Islands, is another species that produces valuable timber for many purposes, such as internal joiners' work, furniture, and the like.

The red cedar, so well known for its being used in making black-lead pencils, is produced by the Virginian cedar (*Juniperus Virginiana*) a native of North America, the West India Islands, and Japan. The tree seldom exceeds 45 feet in height.

The wood of the red cedar is very durable, and is not attacked by worms or insects. It is used for drawers, wardrobes, and various kinds of furniture, for ship-building, and for pencils. Its colour is a brownish red, the sap-wood nearly white, texture nearly uniform; it is brittle, very light, and has a strong and peculiar odour, which renders it unfit to be employed in considerable quantities for internal work.

Its specific gravity is ·650. The cohesive force of cedar, according to Muschenbroek's experiments, is 4875 pounds for a square inch; but the kind is not mentioned*.

Evelyn's Silva, Dr. Hunter's notes; Thunberg's Travels; Miller's Gardener's Dictionary; and Rees's Cyclopædia.

* Intro. ad Phil. Nat. tom. i. p. 414.

# TABLES OF SCANTLINGS, SPECIFIC GRAVITIES, &c.

## No. I.

*Table of the Scantlings of Girders, of Yellow Fir, for different Bearings, from* 10 *to* 36 *feet; Girders* 10 *feet apart.* See Sect. III. art. 138 to 148.

| Length of bearing in feet. | Depth 10 inches. | Depth 11 inches. | Depth 12 inches. | Depth 13 inches. | Depth 14 inches. | Depth 15 inches. | Depth 16 inches. | Depth 17 inches. | Depth 18 inches. | Length of bearing in feet. |
|---|---|---|---|---|---|---|---|---|---|---|
| | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | |
| 10 | 7½ | 5½ | 4 | 3½ | 2¾ | 2¼ | 1¾ | 1½ | 1¼ | 10 |
| 11 | 9 | 6¾ | 5 | 4½ | 3¼ | 2¾ | 2¼ | 2 | 1¾ | 11 |
| 12 | 10½ | 8 | 5¾ | 5 | 3¾ | 3¼ | 2¾ | 2¼ | 2 | 12 |
| 13 | 12½ | 9½ | 6¾ | 5¾ | 4½ | 3¾ | 3 | 2½ | 2½ | 13 |
| 14 | 14½ | 10¾ | 7¾ | 6¾ | 5¼ | 4½ | 3½ | 3 | 2½ | 14 |
| 15 | 16½ | 12½ | 9 | 7¾ | 6 | 5 | 4 | 3½ | 3 | 15 |
| 16 | 18¾ | 14 | 10¼ | 8¾ | 7 | 5¾ | 4¾ | 4 | 3¼ | 16 |
| 17 | | 16 | 11½ | 9¾ | 8 | 6¼ | 5¼ | 4½ | 3¾ | 17 |
| 18 | ...... | 17¾ | 13 | 11 | 8¾ | 7¼ | 6 | 5 | 4 | 18 |
| 19 | ...... | 19¾ | 14½ | 12 | 9¾ | 8 | 6½ | 5½ | 4¾ | 19 |
| 20 | ...... | | 16 | 13½ | 10¾ | 9 | 7¼ | 6 | 5¼ | 20 |
| 21 | ............ | | 17½ | 15 | 12 | 9¾ | 8 | 6¾ | 5¾ | 21 |
| 22 | ............ | | 19½ | 16½ | 13 | 10¾ | 8¾ | 7½ | 6¼ | 22 |
| 23 | ............ | | | 18 | 14¼ | 11½ | 9½ | 8 | 6¾ | 23 |
| 24 | .................. | | | 19½ | 15½ | 12¾ | 10½ | 8¾ | 7½ | 24 |
| 25 | | | | | 16¾ | 13¾ | 11¼ | 9½ | 8 | 25 |
| 26 | | | | | 18¼ | 15 | 12¼ | 10¼ | 8½ | 26 |
| 27 | | | | | 19¾ | 16 | 13 | 11 | 9¼ | 27 |
| 28 | | | | | | 17¼ | 14¼ | 11¾ | 10 | 28 |
| 29 | | | | | | 18½ | 15¼ | 12¾ | 10¾ | 29 |
| | Depth 19 inches. | Depth 20 inches. | Depth 21 inches. | | | | | | | |
| | Breadth in inches. | Breadth in inches. | Breadth in inches. | | | | | | | |
| 30 | 9¾ | 8½ | 7¼ | | | 19¾ | 16¼ | 13½ | 11½ | 30 |
| 31 | 10¼ | 9 | 7¾ | | | | 17¼ | 14½ | 12¼ | 31 |
| 32 | 11 | 9½ | 8¼ | | | | 18½ | 15½ | 13 | 32 |
| 33 | 11¾ | 10 | 8¾ | | | | 19¾ | 16½ | 14 | 33 |
| 34 | 12½ | 10¾ | 9½ | | | | | 17½ | 14¾ | 34 |
| 35 | 13¼ | 11½ | 10 | | | | | 18½ | 15¾ | 35 |
| 36 | 14 | 12 | 10½ | | | | | 19½ | 16½ | 36 |

To find the scantling for a girder for any length of bearing, look in either the right or left hand column for the bearing, and opposite in any of the other columns is the breadth, with the proper depth for that breadth at the head of the column; therefore such a breadth and depth may be selected as will be convenient for the intended purpose. Thus, for a 20 feet bearing a girder may be 16 inches in breadth, and 12 inches deep; or the breadth may be 13½ inches, and the depth 13 inches, and so on; but where there is space to admit of a deep girder it requires less timber. A new series of depths begin for bearings above 29 feet.

This table is calculated by the equation $\frac{74l^2}{d^3}=b$; where $l$ is the length in feet, and $b$ and $d$ the breadth and depth in inches. In the rule in words at length, instead of depth read breadth, in the second line of the rule, art. 139.

## No. II.

*Table of the Scantlings of Binding Joists, of Yellow Fir, for different Bearings, from 5 to 20 feet, when the distance from middle to middle is 6 feet.* See Sect. III. art. 149 and 150.

| Length of bearing in feet. | Depth 6 inches. | Depth 7 inches. | Depth 8 inches. | Depth 9 inches. | Depth 10 inches. | Depth 11 inches. | Depth 12 inches. | Length of bearing in feet. |
|---|---|---|---|---|---|---|---|---|
| | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | Breadth in inches. | |
| 5 | 4¾ | 3 | 2 | | | | | 5 |
| 6 | 6¾ | 4 | 3 | 2 | | | | 6 |
| 7 | | 5½ | 4 | 2¾ | 2 | | | 7 |
| 8 | ........ | 7 | 5¼ | 3¾ | 2¾ | 2 | | 8 |
| 9 | ........ | | 6½ | 4½ | 3½ | 2½ | | 9 |
| 10 | ........ | ........ | 8 | 5½ | 4 | 3 | 2½ | 10 |
| 11 | Depth | Depth | Depth | 6¾ | 5 | 3¾ | 3 | 11 |
| 12 | 13 inches. | 14 inches. | 15 inches. | 8 | 6 | 4½ | 3½ | 12 |
| 13 | Breadth | Breadth | Breadth | | 7 | 5¼ | 4 | 13 |
| 14 | in inches. | in inches | in inches. | | 8 | 5¾ | 4½ | 14 |
| 15 | 4 | 3½ | 2¾ | | 9 | 6¾ | 5¼ | 15 |
| 16 | 4½ | 3¾ | 3¼ | | 10¼ | 7¾ | 6 | 16 |
| 17 | 5¼ | 4¼ | 3½ | | | 8¾ | 6¾ | 17 |
| 18 | 5¾ | 4¾ | 4 | | | 10 | 7½ | 18 |
| 19 | 6½ | 5½ | 4¼ | | | | 8½ | 19 |
| 20 | 7¼ | 6 | 4¾ | | | | 9½ | 20 |

To find the scantling for a binding joist for any bearing, look in either the right or left hand column of the table for the bearing in feet, and opposite the length of bearing, and under some one of the depths at the head of the columns, will be found the breadth required. Thus, if it be required to find the scantling for a binding joist for a 10 feet bearing, 9 inches is a depth that would be suited to the floor; then, opposite 10 feet, in one of the side columns, and under 9 inches at the head of one of the middle columns, we find 5½ inches, the breadth required. If 8 inches had been fixed upon for the depth, it would have required 8 inches in breadth to be equally as stiff as one 9 by 5½. If the bearing be 19 feet, and 13 inches should be of convenient depth, then opposite 19 in the side columns, and under depth 13 inches, we find 6½ inches, the breadth required.

This table is calculated by the rule $\frac{40l^2}{d^3}=b$; where $l$ is the length in feet; and $d$ the depth, and $b$ the breadth, each in inches.

# No. III.

*Table of the Scantlings for Single Joisting, or Bridging Joists, of Yellow Fir, for different Bearings, from* 5 *to* 25 *feet; the distance from middle to middle* 12 *inches.* See Sect. III. art. 137 and 153.

| Length of bearing in feet. | Breadth 1½ in. | Breadth 1¾ in. | Breadth 2 in. | Breadth 2¼ in. | Breadth 2½ in. | Breadth 2¾ in. | Breadth 3 in. | Breadth 3¼ in. | Breadth 3½ in. | Breadth 4 in. | Length of bearing in feet. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | |
| 5 | 5¾ | 5½ | 5¼ | 5 | 4¾ | 4½ | 4⅜ | 4¼ | 4⅛ | 4 | 5 |
| 6 | 6¼ | 6 | 5¾ | 5½ | 5⅜ | 5¼ | 5 | 4⅞ | 4¾ | 4½ | 6 |
| 7 | 7 | 6¾ | 6½ | 6¼ | 6 | 5¾ | 5½ | 5¾ | 5¼ | 5 | 7 |
| 8 | 7¾ | 7½ | 7 | 6¾ | 6½ | 6⅜ | 6¼ | 6 | 5⅞ | 5¾ | 8 |
| 9 | 8½ | 7⅞ | 7½ | 7 | 6⅞ | 6¾ | 6½ | 6¼ | 6 | 5⅞ | 9 |
| 10 | 9 | 8½ | 8 | 7¾ | 7½ | 7¼ | 7 | 6⅞ | 6¾ | 6½ | 10 |
| 11 | 9½ | 9 | 8¾ | 8½ | 8 | 7¾ | 7½ | 7¼ | 7 | 6¾ | 11 |
| 12 | 10 | 9¾ | 9½ | 9 | 8½ | 8¼ | 8 | 7¾ | 7½ | 7¼ | 12 |
| 13 | 10¾ | 10¼ | 9¾ | 9½ | 9 | 8¾ | 8½ | 8¼ | 8 | 7¾ | 13 |
| 14 | 11 | 10½ | 10 | 9¾ | 9½ | 9¼ | 9 | 8¾ | 8½ | 8 | 14 |
| 15 | 11½ | 11 | 10½ | 10 | 9¾ | 9½ | 9¼ | 9 | 8¾ | 8½ | 15 |
| 16 | 12¼ | 11½ | 11 | 10¾ | 10¼ | 10 | 9¾ | 9½ | 9¼ | 8⅞ | 16 |
| 17 | 12¾ | 12 | 11½ | 11¼ | 10¾ | 10½ | 10¼ | 10 | 9¾ | 9¼ | 17 |
| 18 | 13¼ | 12½ | 12 | 11½ | 11¼ | 10¾ | 10½ | 10¼ | 10 | 9½ | 18 |
| 19 | 13¾ | 13 | 12½ | 12 | 11½ | 11¼ | 10¾ | 10½ | 10½ | 10 | 19 |
| 20 | 14¼ | 13¾ | 13 | 12½ | 12 | 11½ | 11¼ | 11 | 10¾ | 10¼ | 20 |
| 21 | 14¾ | 14 | 13½ | 12¾ | 12½ | 12 | 11¾ | 11½ | 11 | 10¾ | 21 |
| 22 | 15 | 14½ | 13¾ | 13¼ | 12¾ | 12½ | 12 | 11¾ | 11½ | 11 | 22 |
| 23 | 15½ | 14¾ | 14 | 13½ | 13 | 12¾ | 12¼ | 12 | 11¾ | 11¼ | 23 |
| 24 | 16 | 15¼ | 14½ | 14 | 13½ | 13¼ | 12¾ | 12½ | 12 | 11¾ | 24 |
| 25 | 16½ | 15½ | 15 | 14½ | 14 | 13½ | 13 | 12¾ | 12½ | 12 | 25 |

To find the scantling for a joist for any bearing, look in either the right or left hand column for the given bearing, and opposite in any of the other columns will be found the depth, with the corresponding breadth at the head of the column; therefore, such a breadth may be taken as is best adapted to the purpose required. Thus, for a 14 feet bearing, a joist 10 by 2 is of the same degree of stiffness as one 9 by 3; or as one of any other depth opposite 14, with the breadth at the top of the column.

This table was calculated by the equation $\left(\frac{l^2}{b}\right)^{\frac{1}{3}} \times 2{\cdot}2 = d$. See art. 137.

## No. IV.

*Table of the Scantlings of Ceiling Joists, of Yellow Fir, for different Bearings, from* 4 *to* 15 *feet; distance from middle to middle* 12 *inches.* See Sect. III. art. 154.

| Length of bearing in feet. | Breadth $1\frac{1}{2}$ inches. | Breadth $1\frac{3}{4}$ inches. | Breadth 2 inches. | Breadth $2\frac{1}{4}$ inches. | Breadth $2\frac{1}{2}$ inches. | Breadth $2\frac{3}{4}$ inches. | Breadth 3 inches. | Length of bearing in feet. |
|---|---|---|---|---|---|---|---|---|
| | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | |
| 4 | $2\frac{1}{4}$ | $2\frac{1}{8}$ | 2 | | | | | 4 |
| 5 | $2\frac{3}{4}$ | $2\frac{5}{8}$ | $2\frac{1}{2}$ | | | | | 5 |
| 6 | $3\frac{3}{8}$ | $3\frac{1}{4}$ | 3 | $2\frac{7}{8}$ | | | | 6 |
| 7 | 4 | $3\frac{3}{4}$ | $3\frac{1}{2}$ | $3\frac{3}{8}$ | $3\frac{1}{4}$ | | | 7 |
| 8 | $4\frac{1}{2}$ | $4\frac{1}{4}$ | 4 | $3\frac{7}{8}$ | $3\frac{3}{4}$ | $3\frac{5}{8}$ | $3\frac{1}{2}$ | 8 |
| 9 | 5 | $4\frac{3}{4}$ | $4\frac{1}{2}$ | $4\frac{3}{8}$ | $4\frac{1}{4}$ | $4\frac{1}{8}$ | 4 | 9 |
| 10 | $5\frac{3}{4}$ | $5\frac{3}{8}$ | 5 | $4\frac{7}{8}$ | $4\frac{3}{4}$ | $4\frac{5}{8}$ | $4\frac{1}{2}$ | 10 |
| 11 | $6\frac{1}{4}$ | $5\frac{7}{8}$ | $5\frac{1}{2}$ | $5\frac{3}{8}$ | $5\frac{1}{4}$ | $5\frac{1}{8}$ | 5 | 11 |
| 12 | $6\frac{3}{4}$ | $6\frac{1}{2}$ | 6 | $5\frac{7}{8}$ | $5\frac{3}{4}$ | $5\frac{3}{8}$ | $5\frac{1}{4}$ | 12 |
| 13 | $7\frac{1}{2}$ | 7 | $6\frac{1}{2}$ | $6\frac{1}{4}$ | 6 | $5\frac{7}{8}$ | $5\frac{3}{4}$ | 13 |
| 14 | 8 | $7\frac{1}{2}$ | 7 | $6\frac{3}{4}$ | $6\frac{1}{2}$ | $6\frac{3}{8}$ | $6\frac{1}{4}$ | 14 |
| 15 | $8\frac{1}{2}$ | $7\frac{7}{8}$ | $7\frac{1}{2}$ | $7\frac{3}{8}$ | $7\frac{1}{4}$ | 7 | $6\frac{3}{4}$ | 15 |

In order to find the scantling of a ceiling joist for any bearing, look for the length of the bearing in either the right or left hand column, and opposite will be found the depth, with the breadth at the top of the column, containing the depth that is most convenient.

Ceiling joists should never have very long bearings, particularly those for ceilings next the roof of a house; as long joists are subject to warp, which breaks the plastering.

The distance from middle to middle should never exceed 12 inches, otherwise the bearing for the laths becomes too long. If the distance from middle to middle exceeds 12 inches, double laths should be used.

This table is calculated by the rule $\frac{\cdot 64 l}{b^{\frac{1}{3}}} = d$; where $l$ is the length, $d$ is the depth, and $b$ the breadth.

## No. V.

*Table of Scantlings of Timbers for different Spans from* 20 *to* 30 *feet, for the Roof shown in* fig. 49, Plate V. See Sect. IV. art. 164.

| Span. | Tie beam A. | King post K. | Principal rafters P. | Braces B. | Purlins C. | Small rafters *r*. |
|---|---|---|---|---|---|---|
| feet. | inches. | inches. | inches. | inches. | inches. | inches. |
| 20 | $9\frac{1}{2} \times 4$ | $4 \times 3$ | $4 \times 4$ | $3\frac{1}{2} \times 2$ | $8 \times 4\frac{3}{4}$ | $3\frac{1}{2} \times 2$ |
| 22 | $9\frac{1}{2} \times 5$ | $5 \times 3$ | $5 \times 3$ | $3\frac{3}{4} \times 2\frac{1}{4}$ | $8\frac{1}{4} \times 5$ | $3\frac{3}{4} \times 2$ |
| 24 | $10\frac{1}{2} \times 5$ | $5 \times 3\frac{1}{2}$ | $5 \times 3\frac{1}{2}$ | $4 \times 2\frac{1}{2}$ | $8\frac{1}{2} \times 5$ | $4 \times 2$ |
| 26 | $11\frac{1}{2} \times 5$ | $5 \times 4$ | $5 \times 4\frac{1}{4}$ | $4\frac{1}{4} \times 2\frac{1}{2}$ | $8\frac{3}{4} \times 5$ | $4\frac{1}{4} \times 2$ |
| 28 | $11\frac{1}{2} \times 6$ | $6 \times 4$ | $6 \times 3\frac{1}{2}$ | $4\frac{1}{2} \times 2\frac{3}{4}$ | $8\frac{3}{4} \times 5\frac{1}{4}$ | $4\frac{1}{2} \times 2$ |
| 30 | $12\frac{1}{2} \times 6$ | $6 \times 4\frac{1}{2}$ | $6 \times 4$ | $4\frac{3}{4} \times 3$ | $9 \times 5\frac{1}{2}$ | $4\frac{3}{4} \times 2$ |

In this table the trusses are supposed to be not more than 10 feet apart, the pitch of the roof about 27 degrees, the covering slate, and the timber yellow fir. The timbers are marked with the letters A, K, P, B, C, and *r*, in the engraving *fig*. 49.

## No. VI.

*Table of Scantlings for Roofs from* 30 *to* 46 *feet Span, to Design* fig. 50, Plate V.; *Trusses* 10 *feet apart.* See Sect. IV. art. 165.

| Span. | Tie beam A. | Queen posts Q. | Principal rafters P. | Straining beam S. | Braces B. | Purlins C. | Small rafters *r*. |
|---|---|---|---|---|---|---|---|
| feet. | inches. | inches. | inches. | inches. | inches. | inches. | inches. |
| 32 | $10 \times 4\frac{1}{2}$ | $4\frac{1}{2} \times 4$ | $5 \times 4\frac{1}{2}$ | $6\frac{3}{4} \times 4\frac{1}{2}$ | $3\frac{3}{4} \times 2\frac{1}{4}$ | $8 \times 4\frac{3}{4}$ | $3\frac{1}{2} \times 2$ |
| 34 | $10 \times 5$ | $5 \times 3\frac{1}{2}$ | $5 \times 5$ | $6\frac{3}{4} \times 5$ | $4 \times 2\frac{1}{2}$ | $8\frac{1}{4} \times 5$ | $3\frac{3}{4} \times 2$ |
| 36 | $10\frac{1}{2} \times 5$ | $5 \times 4$ | $5 \times 5\frac{1}{4}$ | $7 \times 5$ | $4\frac{1}{4} \times 2\frac{1}{2}$ | $8\frac{1}{2} \times 5$ | $4 \times 2$ |
| 38 | $10 \times 6$ | $6 \times 3\frac{3}{4}$ | $6 \times 6$ | $7\frac{1}{4} \times 6$ | $4\frac{1}{2} \times 2\frac{1}{2}$ | $8\frac{1}{2} \times 5$ | $4 \times 2$ |
| 40 | $11 \times 6$ | $6 \times 4$ | $6 \times 6$ | $8 \times 6$ | $4\frac{1}{2} \times 2\frac{1}{2}$ | $8\frac{3}{4} \times 5$ | $4\frac{1}{4} \times 2$ |
| 42 | $11\frac{1}{2} \times 6$ | $6 \times 4\frac{1}{2}$ | $6\frac{1}{4} \times 6$ | $8\frac{1}{4} \times 6$ | $4\frac{1}{2} \times 2\frac{3}{4}$ | $8\frac{3}{4} \times 5\frac{1}{4}$ | $4\frac{1}{2} \times 2$ |
| 44 | $12 \times 6$ | $6 \times 5$ | $6\frac{1}{2} \times 6$ | $8\frac{1}{2} \times 6$ | $4\frac{1}{2} \times 3$ | $9 \times 5$ | $4\frac{3}{4} \times 2$ |
| 46 | $12\frac{1}{2} \times 6$ | $6 \times 5\frac{1}{2}$ | $7 \times 6$ | $9 \times 6$ | $4\frac{3}{4} \times 3$ | $9 \times 5\frac{1}{2}$ | $5 \times 2$ |

Pitch of the roof about 27 degrees, covering slate, and timber yellow fir. The letters refer to the engraving, as in the table above.

The scantlings in these tables are calculated by the rules in Sect. IV. I have put the smallest scantlings that ought to be used for good Riga or Memel timber; of course soft and inferior kinds of timber will require them to be larger.

## No. VII.

*Table of Scantlings for Roofs of from* 46 *to* 60 *feet Span, to Design* fig. 51, Plate VI.; *Trusses* 10 *feet apart.* See Sect. IV. art. 166.

| Span. | Tie beam A. | Queen posts Q. | Posts D. | Principal rafters P. | Straining beam S. | Braces B. | Purlins C. | Small rafters *r*. |
|---|---|---|---|---|---|---|---|---|
| feet. | inches. | inches. | inches. | inches. | inches. | inches. | inches. | inches. |
| 48 | $11\frac{1}{2}\times 6$ | $6\times 5\frac{3}{4}$ | $6\times 2\frac{1}{4}$ | $7\frac{1}{2}\times 6$ | $8\frac{1}{4}\times 6$ | $4\frac{1}{2}\times 2\frac{3}{4}$ | $8\frac{1}{2}\times 5$ | $4\times 2$ |
| 50 | $12\times 6$ | $6\times 6\frac{1}{4}$ | $6\times 2\frac{1}{2}$ | $8\frac{1}{2}\times 6$ | $8\frac{1}{2}\times 6$ | $4\frac{1}{2}\times 2\frac{3}{4}$ | $8\frac{3}{4}\times 5$ | $4\frac{1}{4}\times 2$ |
| 52 | $12\times 6\frac{1}{2}$ | $6\times 6\frac{3}{4}$ | $6\times 2\frac{3}{4}$ | $9\frac{1}{4}\times 6$ | $8\frac{3}{4}\times 6$ | $4\frac{3}{4}\times 2\frac{3}{4}$ | $8\frac{3}{4}\times 5\frac{1}{4}$ | $4\frac{1}{4}\times 2$ |
| 54 | $12\times 7$ | $7\times 6\frac{1}{4}$ | $7\times 2\frac{1}{4}$ | $6\frac{1}{2}\times 7$ | $9\times 6$ | $4\frac{3}{4}\times 2\frac{3}{4}$ | $8\frac{3}{4}\times 5\frac{1}{4}$ | $4\frac{1}{2}\times 2$ |
| 56 | $12\times 8$ | $7\times 6\frac{3}{4}$ | $7\times 2\frac{1}{2}$ | $7\frac{1}{2}\times 7$ | $9\frac{1}{4}\times 6$ | $5\times 2\frac{3}{4}$ | $8\frac{3}{4}\times 5\frac{1}{4}$ | $4\frac{1}{2}\times 2$ |
| 58 | $12\times 8\frac{1}{2}$ | $7\times 7\frac{1}{4}$ | $7\times 2\frac{3}{4}$ | $8\frac{1}{4}\times 7$ | $9\frac{1}{2}\times 7$ | $5\times 2\frac{3}{4}$ | $9\times 5\frac{1}{4}$ | $4\frac{3}{4}\times 2$ |
| 60 | $12\times 9$ | $7\frac{1}{2}\times 7$ | $7\times 3$ | $9\times 7$ | $10\times 7$ | $5\times 3$ | $9\times 5\frac{1}{2}$ | $4\frac{3}{4}\times 2$ |

## No. VIII.

*Table of Scantlings for Roofs from* 60 *to* 90 *feet Span, to Design* fig. 52, Plate VI.; *Trusses* 10 *feet apart.* See Sect. IV. art. 167 and 168.

| Span. | Tie beam A. | Queen posts Q. | Posts D,D. | Principal rafters P. | Straining beam S. | King post K. | Braces B. | Purlins C. | Small rafters *r*. |
|---|---|---|---|---|---|---|---|---|---|
| feet. | inches. | inches. | inches. | inches. | inches. | inches. | inches. | inches. | inches. |
| 65 | $15\times 10\frac{1}{2}$ | $8\times 7$ | $5\times 3$ | $8\times 7\frac{1}{2}$ | $10\frac{1}{2}\times 8$ | $5\times 3$ | $5\times 3\frac{1}{2}$ | $8\frac{1}{4}\times 5$ | $4\times 2$ |
| 70 | $15\times 11\frac{3}{4}$ | $9\times 6\frac{1}{2}$ | $5\times 3\frac{1}{2}$ | $9\times 7$ | $10\frac{1}{2}\times 9$ | $5\times 3\frac{1}{2}$ | $5\times 3\frac{1}{4}$ | $8\frac{1}{2}\times 5$ | $4\frac{1}{4}\times 2$ |
| 75 | $15\times 13\frac{3}{4}$ | $9\times 7\frac{1}{2}$ | $5\times 4$ | $9\times 8$ | $11\frac{1}{4}\times 9$ | $5\times 4$ | $5\times 4\frac{1}{2}$ | $8\frac{3}{4}\times 5$ | $4\frac{1}{2}\times 2$ |
| 80 | $16\times 13$ | $9\times 9$ | $6\times 4$ | $10\frac{1}{2}\times 9$ | $12\times 9$ | $6\times 4$ | $6\times 3\frac{1}{2}$ | $8\frac{3}{4}\times 5\frac{1}{4}$ | $4\frac{1}{2}\times 2$ |
| 85 | $16\times 13\frac{1}{2}$ | $9\frac{1}{2}\times 9$ | $6\times 4\frac{1}{2}$ | $12\times 9$ | $12\frac{3}{4}\times 9$ | $6\times 4\frac{1}{2}$ | $6\times 4$ | $9\times 5\frac{1}{4}$ | $4\frac{3}{4}\times 2$ |
| 90 | $16\times 14$ | $10\times 9\frac{3}{4}$ | $6\times 4\frac{1}{2}$ | $10\frac{1}{2}\times 10$ | $13\times 10$ | $6\times 4\frac{1}{2}$ | $6\times 4$ | $9\times 5\frac{1}{2}$ | $5\times 2$ |

In these tables the pitch of the roof is supposed to be about 27 degrees, the covering slate, and the timber to be good Riga or Memel fir. Inferior timber will require to be of larger dimensions, but the addition of one-fourth of an inch to each dimension will be sufficient for any difference in quality, except it be knotty timber. The letters refer to the parts on the engravings.

## No. IX.

*Table of Scantlings for Roofs from* 55 *to* 65 *feet Span, to Design* fig. 53, Plate VII.; *Trusses* 10 *feet apart.* See Sect. IV. art. 169.

| Span. | Tie beam A. | Queen posts Q. | Principal rafters P. | Straining beam S. | Posts D. | Braces B. |
|---|---|---|---|---|---|---|
| feet. | inches. | inches. | inches. | inches. | inches. | inches. |
| 55 | 12×8 | 8 ×6 | 8 ×8 | 10×8 | 6×4 | 6×4 |
| 60 | 12×9 | 9 ×6 | 9 ×7 | 10×9 | 6×4½ | 6×4½ |
| 65 | 13×9½ | 9½×6½ | 9½×8 | 11×9½ | 6×5 | 6×5 |

In roofs of this design, and between 55 and 65 feet span, the purlins may be 9 inches by 5 inches, and common rafters 5 inches by 2 inches.

## No. X.

*Table of Scantlings for Roofs from* 70 *to* 80 *feet Span, to Design* fig. 54, Plate VII.; *Trusses* 10 *feet apart.* See Sect. IV. art. 170.

| Span. | Tie beam A. | Queen posts Q. | Principal rafters P. | Straining beam S. | |
|---|---|---|---|---|---|
| feet. | inches. | inches. | inches. | inches. | Scantlings of the upper parts may be got from Table No. 5. |
| 70 | 15×11½ | 9½× 8 | 13 × 9½ | 12× 9½ | |
| 75 | 15×14 | 10 × 8½ | 13½×10 | 12×10 | |
| 80 | 16×13 | 10½× 9 | 14 ×10½ | 13×10½ | |
| 85 | 16×14½ | 11 ×10 | 14½×11 | 13×11 | |

## No. XI.

*Table of Scantlings for Roofs from* 20 *to* 32 *feet Span, to Design* fig. 60, Plate VIII.; *Trusses* 10 *feet apart.* See Sect. IV. art. 172.

| Span. | Tie beam. | Curved rib. | Suspending pieces. | | Purlins. | Common rafters. |
|---|---|---|---|---|---|---|
| | | | No. of pairs. | Scantlings of each piece. | | |
| feet. | inches. | inches. | | inches. | inches. | inches. |
| 20 | 8 ×4 | 4 ×4 | 3 | 4×2 | 8 ×5 | 3½×2 |
| 24 | 8 ×4 | 4¾×4 | 3 | 4×2 | 8 ×5 | 4 ×2 |
| 28 | 8 ×5 | 5¼×5 | 3 | 4×2¼ | 8½×5 | 4½×2 |
| 30 | 8½×5 | 6 ×5 | 3 | 4×2¼ | 8½×5 | 4¾×2 |
| 32 | 9 ×5½ | 6 ×5½ | 3 | 4×2½ | 8½×5 | 5 ×2 |

The pitch, &c. the same as the preceding tables.

# No. XII.

*Table of Scantlings for Roofs from* 35 *to* 100 *feet Span, to Design* fig. 57, Plate VIII.; *Trusses* 10 *feet apart.* See Sect. IV. art. 171.

| Span. | Tie beam. | Curved rib. | Suspending pieces. No. of pairs. | Suspending pieces. Scantlings of each piece. | |
|---|---|---|---|---|---|
| feet. | inches. | inches. | | inches. | |
| 35 | 11 × 6 | 6 × 6 | 4 | 4 × $2\frac{1}{2}$ | |
| 40 | 11 × 6 | 7 × 6 | 4 | 4 × $2\frac{3}{4}$ | |
| 45 | 11 × $6\frac{1}{2}$ | 8 × $6\frac{1}{2}$ | 5 | 4 × $2\frac{3}{4}$ | |
| 50 | 11 × 7 | 9 × 7 | 5 | 4 × 3 | |
| 55 | 11 × 7 | 10 × 7 | 6 | 4 × 3 | |
| 60 | 11 × 8 | 10 × 8 | 6 | 4 × $3\frac{1}{4}$ | Purlins 9 × 5 inches. |
| 65 | 11 × 9 | 10 × 9 | 7 | 4 × $3\frac{1}{4}$ | |
| 70 | 11 × $9\frac{1}{2}$ | 11 × $9\frac{1}{2}$ | 7 | $4\frac{1}{2}$ × $3\frac{1}{4}$ | Small rafters 5 × 2 inches. |
| 75 | 11 × 10 | 11 × 10 | 8 | $4\frac{1}{2}$ × $3\frac{1}{4}$ | |
| 80 | 12 × 10 | 12 × 10 | 9 | $4\frac{1}{2}$ × $3\frac{1}{4}$ | |
| 85 | 12 × 11 | $12\frac{1}{2}$ × 11 | 9 | $4\frac{1}{2}$ × $3\frac{1}{2}$ | |
| 90 | 12 × 11 | 14 × 11 | 10 | 5 × $3\frac{1}{4}$ | |
| 95 | 12 × 12 | 14 × 12 | 11 | 5 × $3\frac{1}{2}$ | |
| 100 | 12 × 12 | 15 × 12 | 11 | 5 × 4 | |

The pitch is supposed to be about 27 degrees, the covering slate, and the timber good Riga or Memel fir.

Since this table and the description, art. 171, were written, a roof has been executed on this principle, over the Royal Military Chapel, at Woolwich; of which the span is 50 feet. As the rise was intended to be as little as was consistent with the necessary degree of strength, it was determined by a similar equation to that in art. 270, Sect. VIII. and the scantlings were calculated accordingly. It is covered with lead, and carries a heavy ornamented ceiling. The suspending pieces are of iron.

## No. XIII.

*Table of the Scantlings of Binding Joists, of Yellow Fir, that have to carry a Ceiling only, for different Bearings, from* 5 *to* 12 *feet; distance apart not more than* 6 *feet.* See Sect. III. art. 152.

| Length of bearing in feet. | Breadth 2 inches. | Breadth 2½ inches. | Breadth 3 inches. | Breadth 3½ inches. | Breadth 4 inches. | Breadth 4½ inches. | Breadth 5 inches. | Breadth 5½ inches. | Length of bearing in feet. |
|---|---|---|---|---|---|---|---|---|---|
| | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | |
| 5 | 4¾ | 4½ | 4¼ | 4 | 3¾ | 3½ | | | 5 |
| 6 | 5¾ | 5½ | 5 | 4¾ | 4½ | 4¼ | | | 6 |
| 7 | 6¾ | 6¼ | 6 | 5¾ | 5¼ | 5 | | | 7 |
| 8 | 7¾ | 7¼ | 6¾ | 6½ | 6 | 5¾ | | | 8 |
| 9 | 8¾ | 8 | 7½ | 7¼ | 6¾ | 6½ | 6¼ | | 9 |
| 10 | 9¾ | 8⅞ | 8¼ | 8 | 7½ | 7¼ | 7 | 6¾ | 10 |
| 11 | 10½ | 9¾ | 9¼ | 8¾ | 8¼ | 8 | 7¾ | 7½ | 11 |
| 12 | 11½ | 10¾ | 10 | 9½ | 9¼ | 8¾ | 8½ | 8¼ | 12 |

## No. XIV.

*Table of the Scantlings of Purlins, of Yellow Fir, for Roofs for different Bearings, from* 6 *to* 14 *feet; distances apart* 6 *feet,* 7 *feet,* 8 *feet, and* 9 *feet* See Sect. III. art. 190.

| Length of bearing in feet. | 6 feet apart. | | 7 feet apart. | | 8 feet apart. | | 9 feet apart. | | Length of bearing in feet. |
|---|---|---|---|---|---|---|---|---|---|
| | Depth in inches. | Breadth in inches. | Depth in inches. | Breadth in inches. | Depth in inches. | Breadth in inches. | Depth in inches. | Breadth in inches. | |
| 6 | 6 | 3½ | 6¼ | 3¾ | 6½ | 4 | 6¾ | 4¼ | 6 |
| 7 | 6¾ | 4 | 7 | 4¼ | 7¼ | 4½ | 7½ | 4½ | 7 |
| 8 | 7½ | 4½ | 7¾ | 4¾ | 8 | 4¾ | 8¼ | 5 | 8 |
| 9 | 8¼ | 5 | 8½ | 5¼ | 8¾ | 5¼ | 9 | 5½ | 9 |
| 10 | 8¾ | 5½ | 9¼ | 5½ | 9½ | 5¾ | 9¾ | 5¾ | 10 |
| 11 | 9½ | 5¾ | 9¾ | 5¾ | 10¼ | 6 | 10½ | 6¼ | 11 |
| 12 | 10 | 6 | 10½ | 6¼ | 10¾ | 6½ | 11¼ | 6¾ | 12 |
| 13 | 10¾ | 6½ | 11¼ | 6¾ | 11½ | 7 | 12 | 7¼ | 13 |
| 14 | 11¼ | 6¾ | 11¾ | 7 | 12¼ | 7¼ | 12½ | 7½ | 14 |

Purlins may often be found apparently strong enough of less scantlings than these, but in such cases the common rafters will be found to be stronger than is necessary. But it is most economical to make the rafters no stronger than is necessary to carry the load between the purlins, and the purlins sufficiently strong to carry the rafters.

# No. XV.

*Table of the Scantlings of Common Rafters, for Roofs, for different Bearings, from* 5 *to* 20 *feet; distance apart* 12 *inches.* See Sect. IV. art. 191.

| Length of bearing in feet. | Breadth 1¾ in. | Breadth 2 in. | Breadth 2¼ in. | Breadth 2½ in. | Breadth 2¾ in. | Breadth 3 in. | Breadth 3½ in. | Breadth 4 in. | Breadth 4½ in. | Length of bearing in feet. |
|---|---|---|---|---|---|---|---|---|---|---|
| | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | Depth in inches. | |
| 5 | 3 | 2⅞ | 2¾ | | | | | | | 5 |
| 6 | 3¼ | 3½ | 3¼ | 3⅛ | 3 | | | | | 6 |
| 7 | 4⅛ | 4 | 3¾ | 3⅝ | 3½ | | | | | 7 |
| 8 | 4¾ | 4⅝ | 4⅜ | 4¼ | 4⅛ | 4 | 3¾ | | | 8 |
| 9 | 5¼ | 5⅜ | 5 | 4¾ | 4⅝ | 4½ | 4¼ | | | 9 |
| 10 | 6 | 5¾ | 5½ | 5⅜ | 5⅛ | 5 | 4¾ | 4½ | | 10 |
| 11 | 6½ | 6¼ | 6 | 5¾ | 5⅝ | 5½ | 5¼ | 5 | 4¾ | 11 |
| 12 | 7 | 6¾ | 6½ | 6⅜ | 6¼ | 6 | 5¾ | 5½ | 5¼ | 12 |
| 13 | 7¾ | 7½ | 7¼ | 7 | 6¾ | 6½ | 6¼ | 5¾ | 5⅝ | 13 |
| 14 | 8¼ | 8 | 7¾ | 7½ | 7¼ | 7 | 6¾ | 6¼ | 6⅛ | 14 |
| 15 | 8¾ | 8½ | 8¼ | 8 | 7¾ | 7½ | 7¼ | 6¾ | 6⅝ | 15 |
| 16 | 9½ | 9¼ | 8¾ | 8½ | 8¼ | 8 | 7¾ | 7¼ | 7 | 16 |
| 17 | 10 | 9¾ | 9½ | 9 | 8¾ | 8½ | 8¼ | 8 | 7½ | 17 |
| 18 | 10½ | 10¼ | 10 | 9½ | 9¼ | 9 | 8¾ | 8½ | 8 | 18 |
| 19 | 11 | 10⅞ | 10½ | 10 | 9¾ | 9½ | 9 | 8¾ | 8¼ | 19 |
| 20 | 11¾ | 11½ | 11 | 10½ | 10¼ | 10 | 9½ | 9 | 8¾ | 20 |

Roofs that are covered with plain tiles, or stone slate, will require rafters one-third stronger than is necessary for blue slate. The table will answer for either, for it is calculated for blue slate; and if to the breadth found at the head of a column half of that breadth be added, it will give the breadth required for stone slate, or plain tiles. Thus, for a rafter of 7 feet bearing, 4 inches by 2 inches is sufficient for blue slate; and therefore 4 inches by 3 inches is the scantling for stone slate, or plain tiles.

Purlins also require the same addition to their breadths when the covering is of plain tiles, or stone slates.

## No. XVI.

*Table of Scantlings for Story Posts, to carry two Stories.*

| Height in feet. | 4 feet apart. | 5 feet apart. | 6 feet apart. | 7 feet apart. | 8 feet apart. | Height in feet. |
|---|---|---|---|---|---|---|
| | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | width. thickness. inches, | |
| 6 | 7½ × 4½ | 7¾ × 4¾ | 8¼ × 5 | 8¾ × 5¼ | 9¼ × 5½ | 6 |
| 7 | 7¾ × 4¾ | 8¾ × 5¼ | 9¼ × 5½ | 9½ × 5¾ | 9½ × 5¾ | 7 |
| 8 | 8¾ × 5¼ | 9¼ × 5½ | 9½ × 5¾ | 10 × 6 | 10½ × 6¼ | 8 |
| 9 | 9¼ × 5½ | 9½ × 5¾ | 10½ × 6¼ | 10¾ × 6½ | 10¾ × 6¾ | 9 |
| 10 | 9½ × 5¾ | 10½ × 6¼ | 10¾ × 6½ | 11¼ × 6¾ | 11¾ × 7 | 10 |
| 11 | 10½ × 6¼ | 10¾ × 6½ | 11½ × 6¾ | 11¾ × 7 | 12 × 7¼ | 11 |
| 12 | 10¾ × 6½ | 11¼ × 6¾ | 11¾ × 7 | 12½ × 7½ | 12¾ × 7¾ | 12 |
| 13 | 11¼ × 6¾ | 11¾ × 7 | 12½ × 7½ | 12¾ × 7¾ | 13¼ × 8 | 13 |
| 14 | 11¾ × 7 | 12 × 7¼ | 12¾ × 7¾ | 13¼ × 8 | 13¾ × 8¼ | 14 |
| 15 | 12 × 7¼ | 12½ × 7½ | 13¼ × 8 | 13¾ × 8¼ | 14¼ × 8½ | 15 |
| 16 | 12½ × 7½ | 12¾ × 7¾ | 13¾ × 8¼ | 14¼ × 8½ | 14½ × 8¾ | 16 |

## No. XVII.

*Table of Scantlings for Story Posts, to carry three Stories.*

| Height in feet. | 4 feet apart. | 5 feet apart. | 6 feet apart. | 7 feet apart. | 8 feet apart. | Height in feet. |
|---|---|---|---|---|---|---|
| | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | width. thickness. inches | width. thickness. inches. | |
| 8 | 9½ × 5¾ | 10 × 6 | 10¾ × 6½ | 11¼ × 6¾ | 11¾ × 7 | 8 |
| 9 | 10 × 6 | 10¾ × 6½ | 11¼ × 6¾ | 11¾ × 7 | 12 × 7¼ | 9 |
| 10 | 10¾ × 6½ | 11¼ × 6¾ | 12 × 7 | 12¼ × 7¼ | 12½ × 7¾ | 10 |
| 11 | 11¼ × 6¾ | 11¾ × 7 | 12½ × 7½ | 12¾ × 7¾ | 13¼ × 8 | 11 |
| 12 | 11¾ × 7 | 12½ × 7½ | 13 × 7¾ | 13¼ × 8 | 14 × 8¼ | 12 |
| 13 | 12 × 7¼ | 12¾ × 7¾ | 13¾ × 8¼ | 14 × 8½ | 14½ × 8¾ | 13 |
| 14 | 12¾ × 7¾ | 13¼ × 8 | 14¼ × 8½ | 14½ × 8¾ | 15 × 9 | 14 |
| 15 | 13¼ × 8 | 14¼ × 8½ | 14½ × 8¾ | 15 × 9 | 15¾ × 9¼ | 15 |
| 16 | 13¾ × 8¼ | 14½ × 8¾ | 15 × 9 | 15½ × 9¼ | 16¼ × 9¾ | 16 |

The stories supported are supposed to be constructed with brick, according to the regulations detailed in the Building Act.

## No. XVIII.

*Table of Scantlings for Story Posts, to carry four Stories.*

| Height in feet. | 4 feet apart. | 5 feet apart. | 6 feet apart. | 7 feet apart. | 8 feet apart. | Height in feet. |
|---|---|---|---|---|---|---|
| | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | |
| 8 | 10¼ × 6¼ | 10¾ × 6½ | 11½ × 6¾ | 12 × 7 | 12¼ × 7¼ | 8 |
| 9 | 10¾ × 6½ | 11¾ × 7 | 12 × 7¼ | 12½ × 7½ | 12¾ × 7¾ | 9 |
| 10 | 11¾ × 6¾ | 12 × 7¼ | 12½ × 7¾ | 13¼ × 8 | 13¾ × 8¼ | 10 |
| 11 | 12 × 7¼ | 12½ × 7¾ | 13¼ × 8 | 14 × 8¼ | 14¼ × 8½ | 11 |
| 12 | 12½ × 7½ | 13¼ × 8 | 14¼ × 8½ | 14½ × 8¾ | 14½ × 8¾ | 12 |
| 13 | 13 × 7¾ | 14 × 8¼ | 14½ × 8¾ | 15 × 9 | 15½ × 9¼ | 13 |
| 14 | 13½ × 8¼ | 14¼ × 8¾ | 15 × 9 | 16 × 9½ | 16¼ × 9¾ | 14 |
| 15 | 14½ × 8¾ | 15 × 9 | 16 × 9½ | 16¼ × 9¾ | 16¾ × 10 | 15 |
| 16 | 15 × 9 | 15½ × 9¼ | 16¼ × 9¾ | 16¾ × 10 | 17½ × 10½ | 16 |

## No. XIX.

*Table of Scantlings for Story Posts, to carry five Stories.*

| Height in feet. | 4 feet apart. | 5 feet apart. | 6 feet apart. | 7 feet apart. | 8 feet apart. | Height in feet. |
|---|---|---|---|---|---|---|
| | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | width. thickness. inches. | |
| 8 | 11¼ × 6¾ | 11¾ × 7 | 12¼ × 7½ | 12¾ × 7¾ | 13¼ × 8 | 8 |
| 9 | 11¾ × 7 | 12½ × 7½ | 12¾ × 7¾ | 13¼ × 8 | 14¼ × 8½ | 9 |
| 10 | 12½ × 7½ | 13¼ × 8 | 13¾ × 8¼ | 14¼ × 8½ | 14½ × 8¾ | 10 |
| 11 | 12¾ × 7¾ | 13¾ × 8¼ | 14¼ × 8½ | 15 × 9 | 15½ × 9¼ | 11 |
| 12 | 13¾ × 8¼ | 14¼ × 8½ | 14½ × 8¾ | 16 × 9½ | 16¼ × 9¾ | 12 |
| 13 | 14¼ × 8½ | 15 × 9 | 15½ × 9¼ | 16¼ × 9¾ | 16¾ × 10 | 13 |
| 14 | 14½ × 8¾ | 15½ × 9¼ | 16¼ × 9¾ | 16¾ × 10 | 17½ × 10½ | 14 |
| 15 | 15 × 9 | 16 × 9½ | 16¾ × 10 | 17½ × 10½ | 17¾ × 10¾ | 15 |
| 16 | 16 × 9½ | 16¾ × 10 | 17½ × 10½ | 17¾ × 10¾ | 18¼ × 11 | 16 |

In these tables the stories supported are supposed to be constructed with brick, according to the regulations contained in the act of parliament called the Building Act.

# No. XX.

*Table of the Properties of different Kinds of Timber.*

| Class | Div. | Kind of wood, and state. | Specific gravity. | Weight of the modulus of elasticity in pounds per square inch. | Cohesive force in pounds per square inch. | Comparative Stiff-ness. | Comparative Strength. | Comparative Tough-ness. |
|---|---|---|---|---|---|---|---|---|
| Class I. | Div. I. | Common oak (*Quercus robur*) dry | ·750 | 1,714,500 | 11,880 | 100 | 100 | 100 |
| | | Riga oak, dry | ·688 | 1,610,496 | 12,888 | 93 | 108 | 125 |
| | | Dantzic oak, seasoned | ·755 | 1,998,000 | 12,780 | 117 | 107 | 99 |
| | | American oak | ·867 | 1,958,700 | 10,253 | 114 | 86 | 64 |
| | Div. II. | Beech (*Fagus sylvatica*) dry | ·690 | 1,316,000 | 12,225 | 77 | 103 | 138 |
| | | Alder (*Betula alnus*) dry | ·555 | 1,086,750 | 9,540 | 63 | 80 | 101 |
| | | Plane (*Platanus occidentalis*) dry | ·648 | 1,343,250 | 10,935 | 78 | 92 | 108 |
| | | Sycamore (*Acer pseudo-platanus*) dry | ·590 | 1,036,000 | 9,630 | 59 | 81 | 111 |
| Class II. | Div. I. | Chesnut (*Fagus castanea*) dry | ·535 | 1,147,500 | 10,656 | 67 | 89 | 118 |
| | | Ditto, green | ·875 | 924,570 | 8,100 | 54 | 68 | 85 |
| | | Ash (*Fraxinus excelsior*) dry | ·753 | 1,525,500 | 14,130 | 89 | 119 | 160 |
| | | Elm (*Ulmus campestris*) dry | ·544 | 1,343,000 | 9,720 | 78 | 82 | 86 |
| | | Acacia (*Robinia pseudo-acacia*) green | ·820 | 1,687,500 | 11,227 | 98 | 95 | 92 |
| | Div. II. | Spanish mahogany, dry | ·853 | 1,255,500 | 7,560 | 73 | 67 | 61 |
| | | Honduras ditto, dry | ·560 | 1,593,000 | 11,475 | 93 | 96 | 99 |
| | | Walnut (*Juglans regia*) green | ·920 | 837,000 | 8,775 | 49 | 74 | 111 |
| | | Teak (*Tectona grandis*) | ·744 | 2,167,074 | 12,915 | 126 | 109 | 94 |
| | | Poplar (*Populus dilatata*) dry | ·374 | 763,000 | 5,928 | 44 | 50 | 57 |
| | | Abele (*Populus alba*) dry | ·511 | 1,134,000 | 10,260 | 66 | 86 | 112 |
| | Div. III. | Cedar of Libanus (*Pinus cedrus*) dry | ·486 | 486,000 | 7,420 | 28 | 62 | 106 |
| | | Riga fir (*Pinus sylvestris*) dry | ·480 | 1,687,500 | 9,540 | 98 | 80 | 64 |
| | | Memel fir (ditto) dry | ·544 | 1,957,750 | 9,540 | 114 | 80 | 56 |
| | | Mar Forest fir (ditto) | ·684 | 845,066 | 7,323 | 49 | 61 | 76 |
| | | Planted Scotch fir (ditto) dry | ·460 | 951,750 | 7,110 | 55 | 60 | 65 |
| | | Christiana white deal (*Pinus abies*) dry | ·512 | 1,804,000 | 12,346 | 104 | 104 | 104 |
| | | American white spruce (*Pinus alba*) dry | ·465 | 1,244,000 | 10,296 | 72 | 86 | 102 |
| | | Planted spruce (*Pinus abies*) dry | ·555 | 1,393,975 | 8,370 | 81 | 70 | 60 |
| | | Weymouth pine (*Pinus strobus*) dry | ·460 | 1,633,500 | 11,835 | 95 | 99 | 103 |
| | | Pitch pine | ·660 | 1,252,200 | 9,796 | 73 | 82 | 92 |
| | | Larch (*Pinus larix*) dry | ·643 | 1,363,500 | 12,240 | 79 | 103 | 134 |

In the last three columns of this table oak is made the standard of comparison.

# No. XXI.

*Table of the Specific Gravity and Weight of a Cubic Foot of different Woods.*

| Kind of wood, and state. | Specific gravity. | Weight of a cubic foot in pounds. |
|---|---|---|
| Abele, dry | ·511 T. | 32·00 |
| Acacia (false) green | ·820 E. | 51·25 |
| —— dry | ·791 H. | 49·43 |
| —— dry | ·748 T. | 46·75 |
| —— (three thorned) | ·676 H. | 42·25 |
| Alder | ·800 M. | 50·00 |
| —— dry | ·555 E. | 34·68 |
| Almond tree | 1·102 H. | 68·87 |
| Apple tree | ·793 M. | 49·56 |
| Apricot tree | ·789 H. | 49·31 |
| Arbor vitæ (Chinese) | ·560 H. | 35·00 |
| Ash (heart-wood) dry | ·845 P. | 52·81 |
| —— dry | ·832 W. | 52·00 |
| —— young wood, dry | ·811 T. | 50·68 |
| —— | ·800 J. | 50·00 |
| —— | ·760 B. | 47·50 |
| —— (old tree) dry | ·753 T. | 47·06 |
| —— dry | ·690 E. | 43·12 |
| Bay tree | ·822 M. | 51·37 |
| Beech (meanly dry) | ·854 P. | 53·37 |
| —— | ·852 M. | 53·25 |
| —— | ·720 H. | 45·00 |
| —— | ·696 B. | 43·50 |
| —— dry | ·690 E. | 43·12 |
| Birch, dry | ·720 E. | 45·00 |
| Box (Dutch) | 1·328 M. | 83·00 |
| —— dry | 1·030 J. | 64·37 |
| —— | 1·031 P. | 64·43 |
| —— from | 1·024 B. | 64·00 |
| to | ·960 B. | 60·00 |
| —— dry | ·950 W. | 59·37 |
| —— Turkey | ·949 R. | 59·31 |
| Brazil wood (red) | 1·031 M. | 64·43 |
| Canary wood | ·723 R. | 45·18 |
| Cedar (Indian) | 1·315 M. | 82·18 |
| —— (Canadian) | ·753 C. | 47·06 |
| —— (Virginian red) dry | ·650 T. | 40·62 |
| —— (Palestine) | ·596 M. | 37·25 |
| —— (American) | ·560 M. | 35·00 |
| —— seasoned | ·453 C. | 28·31 |
| Cedar of Libanus | ·603 H. | 37·68 |
| —— dry | ·486 T. | 30·37 |
| Cherry tree | ·741 H. | 46·31 |
| —— dry | ·672 T. | 42·00 |
| Chesnut (sweet) green | ·875 E. | 54·68 |
| —— | ·685 H. | 42·81 |
| Chesnut (sweet,) dry | ·606 T. | 37·95 |
| —— another specimen, dry | ·535 T. | 33·45 |
| —— (horse) | ·657 H. | 41·06 |
| —— dry | ·596 T. | 37·28 |
| —— another specimen, dry | ·483 T. | 30·18 |
| Cocoa wood | 1·040 M. | 65·00 |
| Cork | ·240 M. | 15·00 |
| Crab tree, meanly dry | ·765 P. | 47·81 |
| Cypress | ·655 H. | 40·93 |
| —— (Spanish) | ·644 M. | 40·25 |
| Deal, white. See fir. | | |
| —— yellow. See pine. | | |
| Ebony (American) | 1·331 M. | 83·18 |
| —— (Indian) | 1·209 M. | 75·56 |
| —— | 1·108 R. | 69·25 |
| Elder tree | ·695 M. | 43·43 |
| Elm, green | ·940 C. | 58·75 |
| —— | ·693 S. | 44·41 |
| —— seasoned | ·588 C. | 36·75 |
| —— | ·553 B. | 34·56 |
| —— (common) dry | ·544 E. | 34·00 |
| —— wych, young tree, green | ·763 E. | 47·68 |
| —— ditto, dry | ·684 T. | 42·75 |
| Filbert tree | ·600 M. | 37·50 |
| Fir (Norway spruce) | ·512 T. | 32·00 |
| — (white American spruce) | ·465 T. | 29·06 |
| — (silver) green | ·531 Wi. | 33·20 |
| — dry | ·403 Wi. | 25·22 |
| — (Scotch.) See pine. | | |
| Fustic | ·817 R. | 51·06 |
| Hazel | ·606 M. | 37·87 |
| Hickery | ·929 S. | 58·06 |
| Hornbeam | ·760 H. | 47·50 |
| Jasmine (Spanish) | ·770 M. | 48·12 |
| Juniper wood | ·556 | 34·75 |
| Laburnum | ·843 T. | 52·70 |
| Lance wood | 1·038 L. | 64·87 |
| —— dry | ·943 R. | 58·93 |
| Larch, green | ·858 Wi. | 53·63 |
| —— (red wood) seasoned | ·640 T. | 40·00 |
| —— dry | ·612 Wi. | 38·31 |
| —— dry | ·496 T. | 31·00 |

| Kind of wood, and state. | Specific gravity. | Weight of a cubic foot in pounds. |
|---|---|---|
| Larch (white wood) seasoned | ·364 T. | 22·75 |
| Lemon tree | ·703 | 43·93 |
| Letter wood | 1·286 C. | 80·37 |
| Lignum vitæ | 1·333 M. | 83·31 |
| —— | 1·327 P. | 82·93 |
| Lime tree | ·604 M. | 37·75 |
| —— | ·564 H. | 35·25 |
| —— | ·480 T. | 30·00 |
| Logwood | ·913 P. | 57·06 |
| Mahogany (Spanish) dry | ·852 T. | 53·30 |
| —— dry | ·816 W. | 51·00 |
| —— (Honduras) dry | ·560 T. | 35·00 |
| Maple (Norway) | ·795 L. | 49·68 |
| —— dry | ·755 P. | 47·18 |
| —— (common) dry | ·624 T. | 32·75 |
| Medlar tree | ·944 M. | 59·00 |
| Mulberry tree (Spanish) | ·897 M. | 56·06 |
| Oak (live) half seasoned | 1·216 Ch. | 76·03 |
| —— (English) green | 1·113 C. | 69·56 |
| —— (French) green | 1·063 Bu. | 66·43 |
| —— (Irish bog) | 1·046 C. | 65·37 |
| —— (evergreen) | ·994 H. | 62·25 |
| —— (Adriatic) | ·993 B. | 62·06 |
| —— (black bog) dry | ·965 R. | 60·31 |
| —— (white American) half seasoned | ·908 Ch. | 56·75 |
| —— (*Quercus sessiliflora*) dry | ·879 T. | 54·97 |
| —— (American) white | ·840 H. | 52·50 |
| —— (Provence) seasoned | ·828 D. | 51·75 |
| —— (*Quercus robur*) dry | ·807 T. | 50·47 |
| —— (English) seasoned | ·777 C. | 48·56 |
| —— (Dantzic) seasoned | ·755 T. | 47·24 |
| —— (American) red | ·752 L. | 47·00 |
| —— (Riga) dry | ·688 T. | 43·00 |
| —— (English) from an old tree, dry | ·625 T. | 39·06 |
| Olive tree | ·927 M. | 57·93 |
| Orange tree | ·705 M. | 44·06 |
| Pear tree, dry | ·708 T. | 44·25 |
| —— | ·646 B. | 40·37 |
| Pine (American pitch) dry | ·936 T. | 58·5 |
| —— (ditto) seasoned | ·741 C. | 46·31 |
| —— (pinaster) green | ·837 Wi. | 52·35 |

| Kind of wood, and state. | Specific gravity. | Weight of a cubic foot in pounds. |
|---|---|---|
| Pine (Scotch) green | ·816 Wi. | 51·08 |
| —— (Mar Forest) | ·696 B. | 43·50 |
| —— (planted Scotch) dry | ·529 T. | 33·06 |
| —— (Scotch) dry | ·429 Wi. | 26·81 |
| —— (Memel) dry from | ·553 | 34·56 |
| —— (Memel) dry to | ·544 T. | 34·00 |
| —— (Riga) dry from | ·480 | 30·00 |
| —— (Riga) dry to | ·466 T. | 29·12 |
| —— (Weymouth) dry | ·460 T. | 28·75 |
| —— (American) dry | ·368 T. | 23·00 |
| Plane (occidental) dry | ·648 E. | 40·50 |
| —— (oriental) | ·538 H. | 33·62 |
| Plane tree (common.) See sycamore | | |
| Plum tree | ·785 M. | 49·06 |
| —— | ·663 P. | 41·43 |
| Poon (seasoned) | ·576 C. | 36·00 |
| Poplar (Spanish, white) | ·529 M. | 33·06 |
| —— (black) dry | ·421 T. | 26·31 |
| —— (Lombardy) dry | ·374 E. | 24·37 |
| Quince tree | ·705 M. | 44·06 |
| Sassafras | ·482 P. | 30·12 |
| Satin wood | ·952 R. | 59·50 |
| Saul (Bengal) seasoned | ·994 L. | 62·12 |
| Service tree | ·742 H. | 46·37 |
| Sissoo (Bengal) seasoned | ·889 L. | 55·52 |
| Stink wood (seasoned) | ·681 C. | 42·56 |
| Sycamore | ·645 H. | 40·31 |
| —— dry | ·590 E. | 36·87 |
| Teak, dry | ·832 Ch. | 52·00 |
| —— | ·745 B. | 46·56 |
| —— seasoned | ·657 C. | 41·06 |
| Tulip tree | ·477 H. | 29·81 |
| Vine | 1·237 M. | 77·31 |
| Walnut tree, green | ·920 E. | 57·50 |
| —— (American) | ·735 H. | 45·93 |
| —— (French) | ·671 M. | 41·93 |
| —— dry | ·616 T. | 38·50 |
| Willow, green | ·619 E. | 38·68 |
| —— dry from | ·568 | 35·50 |
| —— dry to | ·404 T. | 25·25 |
| Yellow wood, seasoned | ·657 C. | 41·06 |
| Yew (Spanish) | ·807 M. | 50·43 |
| —— (Dutch) | ·788 M. | 49·25 |
| —— | ·788 H. | 48·62 |

The letters following the specific gravities refer to the authorities; B. Barlow; Bu. Buffon; C. Couch; Ch. from Chapman on Preservation of Timber; E. Ebbels; H. from Rondelet's table; J. Jurin; L. Layman; M. Muschenbroek; P. Philosophical Transactions, vol. i. Lowthorp's Abridgment; R. Ralph Tredgold, who collected this and the following table; S. Scoresby; T. from my own experiments; W. Watson (Bishop;) and Wi. Wiebeking.

# No. XXII.

*Table of the Specific Gravity and Weight of a Cubic Foot of various Substances.*

| Name of the substance. | Specific gravity. | Weight of a cubic foot in pounds. | Name of the substance. | Specific gravity. | Weight of a cubic foot in pounds. |
|---|---|---|---|---|---|
| Air (atmospheric) | ·0012 | ·075 | Coal (Cannel) | 1·272 Th. | 79·50 |
| Alabaster. See gypsum. | | | —— (Newcastle caking) | 1·269 Th. | 79·31 |
| Basalt { from | 3·00 | 187·50 | Copper (British sheet) | 8·785 Ha. | 549·06 |
| Basalt { to | 2·478 | 154·87 | —— (British cast) | 8·607 Ha. | 537·93 |
| —— (Fairhead) | 2·95 K. | 184·37 | Earth (common) { from | 1·520 | 95·00 |
| —— (Derbyshire) | 2·921 W. | 182·56 | Earth (common) { to | 1·984 | 124·00 |
| —— (Giant's Causeway) | 2·90 K. | 181·25 | —— (loamy or strong) | 2·016 | 126·00 |
| —— | 2·864 Br. | 179·00 | —— (rammed) | 1·584 Pa. | 99·00 |
| —— (Rowley rag) | 2·478 K. | 154·87 | —— (loose or sandy) | 1·520 | 95·00 |
| Bees' wax (yellow) | ·965 | 60·31 | Firestone | 1·800 | 112·50 |
| Bismuth (cast) | 9·822 | 613·87 | Flint { from | 2·580 | 161·25 |
| Bitumen, of Judea | 1·104 | 69·00 | Flint { to | 2·630 Th. | 164·37 |
| Brass (wire drawn) | 8·544 | 534·00 | —— (black Cambridge) | 2·592 W. | 162·00 |
| —— (plate) | 8·441 W. | 527·56 | Freestone. See stone. | | |
| —— (cast) | 8·100 P. | 506·25 | Glass, white flint | 3·000 | 187·50 |
| Brick (common) { from | 1·557 | 97·31 | —— plate | 2·760 | 172·50 |
| Brick (common) { to | 2·000 | 125·00 | —— crown | 2·520 | 157·50 |
| —— (red) | 2·168 Re. | 135·50 | Gold, pure cast | 19·361 Br. | 1210·06 |
| —— (pale red) | 2·085 Re. | 130·31 | —— standard | 17·724 Th. | 1107·75 |
| —— | 1·857 Be. | 116·06 | Granite { from | 2·999 | 187·47 |
| —— (common London stock) | 1·841 T. | 115·06 | Granite { to | 2·538 K. | 158·62 |
| | | | —— (Guernsey) | 2·999 W. | 187·47 |
| —— paving (English clinker) | 1·653 R. | 103·31 | —— (Aberdeen gray) | 2·664 R. | 166·5 |
| | | | —— (Cornish) | 2·662 Re. | 166·37 |
| —— (Dutch clinker) | 1·482 R. | 92·62 | —— (ditto) | 2·653 R. | 165·81 |
| —— (Welsh fire) | 2·408 T. | 150·50 | —— (Aberdeen red) | 2·643 R. | 165·18 |
| Brickwork, about | | 95·00 | —— (Cornish) | 2·624 T. | 164·00 |
| Cement (Roman) and sand in equal parts | 1·817 T. | 113·56 | Gravel | 1·749 P. | 109·32 |
| | | | Gunpowder (solid) | 1·745 | 109·06 |
| —— alone (cast) | 1·600 R. | 100·00 | —— (shaken) | ·922 | 57·62 |
| Chalk { from | 2·315 | 144·68 | Gypsum (plaster stone) | 2·286 W. | 142·87 |
| Chalk { to | 2·657 Th. | 166·06 | Iron (bar) { from | 7·600 | 475·00 |
| —— (Cambridge clunch) | 2·657 W. | 166·06 | Iron (bar) { to | 7·800 K. | 487·50 |
| —— (Dorking) | 1·869 R. | 116·81 | —— hammered | 7·763 M. | 485·18 |
| Charcoal from birch | ·542 K. | 33·87 | —— not hammered | 7·600 M. | 475·00 |
| —— from fir | ·441 K. | 27·56 | —— (cast) { from | 7·600 | 475·00 |
| —— from oak | ·332 K. | 20·75 | —— (cast) { to | 7·200 Th. | 450·00 |
| —— from pine | ·280 K. | 17·50 | —— horizontal ditto | 7·113 Re. | 444·56 |
| Clay (potter's) { from | 1·800 | 112·50 | —— vertical castings | 7·074 Re. | 442·12 |
| Clay (potter's) { to | 2·085 K. | 130·31 | Ivory | 1·826 P. | 114·12 |
| —— (common) | 1·919 Be. | 119·93 | Lead (milled) | 11·407 Th. | 712·93 |
| —— with gravel | 2·560 | 160·00 | —— (cast) | 11·352 Br. | 709·50 |
| —— slate. See slate. | | | —— black. See plumbago. | | |
| Coak | ·744 K. | 46·50 | Lime, quick | ·843 Be. | 52·68 |
| Coal (Kilkenny) | 1·526 K. | 95·37 | Limestone. See stone, and marble. | | |
| —— (Glasgow splint) | 1·290 Th. | 80·62 | | | |

| Name of the substance. | Specific gravity. | Weight of a cubic foot in pounds. |
|---|---|---|
| Loam. See earth. | | |
| Marble .......... from | 2·840 | 177·50 |
| to | 2·580 | 161·25 |
| —— Parian white .... | 2·837 K. | 177·31 |
| —— veined white .... | 2·726 Re. | 170·37 |
| —— Carrara white.... | 2·717 K. | 169·81 |
| —— —— blue .... | 2·713 K. | 169·56 |
| —— Italian black .... | 2·712 K. | 169·50 |
| —— Derbyshire entrochal ............ | 2·709 R. | 169·31 |
| —— Saxon gray...... | 2·700 K. | 168·75 |
| —— Brabant black .. | 2·697 Re. | 168·56 |
| —— Derbyshire black | 2·690 W. | 168·12 |
| —— Namur black .... | 2·682 R. | 167·62 |
| —— Sienna yellow .. | 2·677 K. | 167·31 |
| —— Pallion brown figured............ | 2·586 R. | 161·62 |
| Marl ........... from | 1·600 | 100·00 |
| to | 2·870 Th. | 179·37 |
| Mercury (fluid) ........ | 13·568 Br. | 848·00 |
| Mortar................ | 1·715 Be. | 107·18 |
| —— of river sand 3 parts, of lime in paste 2 parts............ | 1·615 Ro. | 100·93 |
| —— ditto, ditto, well beat together ...... | 1·893 Ro. | 118·31 |
| —— of pit sand 3 parts, of lime in paste 2 parts............ | 1·588 Ro. | 99·25 |
| —— ditto, ditto, well beat together ...... | 1·903 Ro. | 118·93 |
| —— of pounded tile 3 parts, of quicklime 2 parts ............ | 1·457 Ro. | 91·06 |
| —— ditto, ditto, well beat together ...... | 1·663 Ro. | 103·93 |
| —— common, of chalk, lime, and sand, dry .............. | 1·550 R. | 96·87 |
| —— the lining of an antique reservoir near Rome ............ | 1·549 Ro. | 96·81 |
| —— from the interior of an old wall at Rome | 1·414 Ro. | 88·37 |
| —— lime, sand, and hair, used for plastering, dry .......... | 1·384 R. | 86·50 |
| Oolite. See stone, roe. | | |
| Peat (hard)............ | 1·329 | 83·06 |
| Pebble (English) ....... | 2·609 | 163·06 |

| Name of the substance. | Specific gravity. | Weight of a cubic foot in pounds. |
|---|---|---|
| Pewter................ | 7·248 | 453·00 |
| Pitch ................ | 1·150 P. | 71·87 |
| Plaster (cast) .......... | 1·286 Be. | 80·37 |
| Platina, pure ........... | 21·531 Th. | 1345·68 |
| Plumbago, or black lead . | 2·267 | 141·68 |
| Porphyry (green) ...... | 2·875 | 179·68 |
| —— (red) ........ | 2·793 | 174·56 |
| Potstone ........ from | 3·000 | 187·50 |
| to | 2·768 K. | 173·00 |
| Puzzolana ....... from | 2·570 | 160·62 |
| to | 2·850 K. | 178·12 |
| Quartz (crystallized) .... | 2·655 | 165·93 |
| Roe-stone. See stone. | | |
| Road grit. See sand. | | |
| Sand (pure quartz) ..... | 2·750 | 171·87 |
| —— river ........... | 1·886 Be. | 117·87 |
| —— River Thames (best) | 1·638 T. | 102·37 |
| —— pit (clean but coarse) | 1·610 T. | 100·62 |
| —— pit (fine grained and clean) ........ | 1·523 T. | 95·18 |
| —— scraped from London roads (road grit) | 1·494 T. | 93·37 |
| —— pit (very fine grained) | 1·480 T. | 92·50 |
| —— river Thames (inferior) ............ | 1·454 T. | 90·87 |
| Sandstone. See stone. | | |
| Serpentine, Anglesey green | 2·683 R. | 167·68 |
| —— blackish green | 2·574 K. | 160·87 |
| —— dark reddish brown ............ | 2·561 K. | 160·06 |
| Silver, pure cast ........ | 10·474 Br. | 654·62 |
| —— standard ........ | 10·312 Th. | 644·50 |
| Slate, Welsh .......... | 2·888 K. | 180·50 |
| —— Anglesey ........ | 2·876 K. | 179·75 |
| —— Westmoreland, pale blue .......... | 2·791 W. | 174·43 |
| —— dark blue .............. | 2·781 W. | 173·81 |
| —— pale greenish blue ...... | 2·768 W. | 173·00 |
| —— blackish blue, used for floors | 2·758 W. | 172·37 |
| —— Welsh rag ...... | 2·752 K. | 172·00 |
| —— Westmoreland fine grained pale blue | 2·732 W. | 170·75 |
| —— Cornwall grayish blue .......... | 2·512 K. | 157·00 |
| Stone, Bath (roe-stone) .. | 2·494 K. | 155·87 |
| —— ......... | 1·975 R. | 123·43 |
| —— Blue-lias (limestone) | 2·467 R. | 154·18 |

| Name of the substance. | Specific gravity. | Weight of a cubic foot in pounds. |
|---|---|---|
| Stone, Bromley-fall sandstone ........ | 2·506 Re. | 156·62 |
| ———— ....... | 2·261 R. | 141·31 |
| —— Bristol stone ...... | 2·510 | 156·87 |
| —— Burford (dry piece) | 2·049 P. | 128·06 |
| —— Caen (calcareous sandstone) ........ | 2·108 R. | 131·75 |
| —— Clitheroe limestone | 2·686 W. | 167·87 |
| —— Collalo, white (sandstone) ........ | 2·423 Re. | 151·43 |
| ———— ..... | 2·040 R. | 127·50 |
| —— Craigleith (sandstone) ............ | 2·452 Re. | 153·25 |
| ———— ......... | 2·360 R. | 147·50 |
| —— Derbyshire (red friable sandstone) .... | 2·346 Re. | 146·62 |
| —— Dundee .......... | 2·530 Re. | 158·12 |
| ———— ......... | 2·517 T. | 157·31 |
| —— (grindstone) ...... | 2·143 | 133·93 |
| —— Hedding-stone, lax kind .............. | 2·029 P. | 126·81 |
| —— Hilton (sandstone) | 2·177 R. | 136·06 |
| —— Kentish rag ...... | 2·675 R. | 167·18 |
| —— Ketton (roe-stone) . | 2·494 K. | 155·87 |
| ———— ......... | 2·058 R. | 128·62 |
| —— Kincardine (sandstone) ............ | 2·448 T. | 153·00 |
| —— Limerick (black compact limestone) . | 2·598 Re. | 162·37 |
| —— Pennarth (limestone) | 2·653 W. | 165·81 |
| —— Portland (roe-stone) | 2·461 W. | 153·81 |

| Name of the substance. | Specific gravity. | Weight of a cubic foot in pounds. |
|---|---|---|
| Stone, Portland, (roe-stone) | 2·423 Re. | 151·43 |
| ———— | 2·113 R. | 132·06 |
| —— pumice .......... | ·629 R. | 39·31 |
| —— Purbeck .......... | 2·680 W. | 167·50 |
| ———— ......... | 2·599 Re. | 162·43 |
| —— Roach Abbey (magnesian limestone) | 1·893 R. | 118·31 |
| —— (Tottenhoe calcareous sandstone).... | 1·800 T. | 112·50 |
| —— Woodstock flagstone | 2·614 K. | 163·37 |
| —— Yorkshire paving .. | 2·507 Re. | 156·68 |
| ———— ... | 2·356 R. | 147·25 |
| Stonework, mean weight according to Belidor about ............ | | 107·00 |
| Shingle ................ | 1·424 Pa. | 89·00 |
| Steel ........... from | 7·780 | 486·25 |
| Steel ........... to | 7·840 Th. | 490·00 |
| Syenite (Mount Sorrel) .. | 2·621 | 163·81 |
| Tile (common plain) .... | 1·858 R. | 116·15 |
| —— ................ | 1·815 Be. | 113·43 |
| Tin, hammered ........ | 7·299 Br. | 456·18 |
| —— pure cast ........ | 7·291 Br. | 455·68 |
| Toadstone (Derbyshire).. | 2·921 W. | 182·56 |
| Tufa (Roman) ......... | 1·217 Ro. | 76·06 |
| Water, sea ........... | 1·027 Th. | 64·18 |
| —— rain .......... | 1·000 | 62·50 |
| Whinstone (Scotch) .... | 2·760 W. | 172·50 |
| Wood ashes .......... | ·933 P. | 58·32 |
| Wood petrified ........ | 2·341 P. | 146·31 |
| Zinc ............... | 7·028 W. | 439·25 |

Part of the letters of reference are explained in a note to the preceding table, the rest are as follow: Be. Belidor; Br. Brisson; Ha. Hatchet; K. from Kirwan's Mineralogy; Re. Rennie, Philosophical Magazine, vol. liii.; Ro. Rondelet; Th. from Dr. Thomson's System of Chemistry, 5th edition; and Pa. Pasley, Course of Military Instruction.

In bodies of a porous nature, the specific gravity, as given by the greater part of the tables I have consulted, is much above the real weight of a given bulk of the material, as compared with water. The cause of this difference is the absorption which takes place when the body to be tried is immersed in water. Let A be the weight of a body in air, W its weight in water, $a$ the weight of water it absorbs, and S the specific gravity; then $\frac{A}{A+a-W}=S$. When the absorption is nothing, or $a=o$; then $\frac{A}{A-W}=S$, which is the same as the common rule.

By the equation $\frac{A}{A+a-W}=S$, the specific gravities in the table marked R and T have been determined. But this method does not apply to sand and other loose materials; therefore, to find the specific gravity of sand, a vessel, which

# ADDENDUM TO SECTION II.

## *On the Resilience of Timber.*

Resilience, or the power of resisting a body in motion, is a kind of strength which is of importance in some cases, as it is well known that many bodies that are capable of resisting an enormous degree of pressure may be fractured by the stroke of a small hammer, moving with a moderate velocity.

As the resilience of materials had been considered by other writers, in as far as regards the resistance to fracture only, I did not include it in arranging the objects to be treated in Sect. II. because I had not at that time satisfied myself that my conclusions were consistent with the laws of resilience as determined by experiment: but now, having made such trials as convinced me of their accuracy, I add them here rather than omit them; as in floors and other parts of buildings, &c. we make the resistance to a body in motion the measure of their stiffness; therefore the stiffness to resist a body in motion ought to be considered in a work on carpentry.

If a beam be supported at both ends, and W be the weight corresponding to $\delta$, the deflexion which the beam may take without injury to the structure; and $x$ be any variable degree of deflexion: also $w$ the weight of the falling body, $h$ the height of the fall, and $\sqrt{4gh}$ the velocity with which the weight $w$ strikes the beam. Then, $\delta : x ::$ $W : \frac{Wx}{\delta}$ = the resistance at any deflexion $x$; and $\frac{Wx}{\delta w}$ = the retarding force there. By

when filled contained a known weight of water, was filled with the sand to be tried, and weighed. The vessel I used contained 1300 grains of water; therefore, as 1300 : weight of the sand :: 1 : specific gravity of the sand.

By the method of mixing equal volumes of water and sand, a solid specimen of quartz would be of the same specific gravity as its sand would be; but it is well known that a stone crushed into sand occupies more space than the solid stone did; and therefore the method is erroneous.

The specific weight of a cohesive earth, such as clay or loam, is best got by cutting a cubical piece, and carefully measuring and weighing it. This method is given by Kirwan in his Essay on the Analysis of Soils, and is accurate enough for business.

the laws of variable motion $-v\dot{v}=\frac{2gWx\dot{x}}{\delta w}$*; of which the fluents are $-v^2=\frac{2gWx^2}{\delta w}$; but, when $x=o$, $v^2=4gh$; therefore, $4gh-v^2=\frac{2gWx^2}{\delta w}$. Also, when $x=\delta$, $v=o$; and we have $2hw=W\delta$.

Now in Sect. II. art. 80, equation (2.) it has been shown, that $W=\frac{BD^3}{aL^2}$; and considering the deflexion, $\delta$, constant, and substituting for W its value, we have $hw : \frac{BD^3}{L^2}$: consequently, the resistance to resilience is regulated by the same proportions as the stiffness of beams; and the same rules apply to both, merely requiring different constant numbers.

The effect of a body in motion is expressed by $h\times w$; that is, by the weight multiplied into the height of the fall: thus, a weight of 100 pounds falling from a height of 3 inches produces the same effect as one pound falling 300 inches; or as a body of 100 pounds weight moving horizontally at the rate of 4 feet per second.

The mass of the resisting body has not been considered in this inquiry, but it is obvious that its effect is considerable, and, if the space permitted, it might easily be illustrated by many popular examples.

* Dr. Hutton's Course of Mathematics, vol. ii. p. 331, 5th edit.

# INDEX.


A.

PAGE

ABELE described . . . . . . . . 207
——— experiments on the stiffness of 36
——————————— strength of 44
Abutments, curved, for joints . . . . 142
——— for bridges . . . . . . . 122
Acacia described . . . . . . . . . 203
——— experiments on the stiffness of . 36
——————————— strength of . 44
Acer (see sycamore) . . . . . . . 197
Age of trees . . . . . . . . . . . 151
Air, circulation of, when of use in stopping the dry rot . . . . . . . . . 172
Alder described . . . . . . . . . . 195
——— felled in summer durable . . . . 153
——— experiments on the stiffness of . . 36
——————————— strength of . . 44
Alkalies, effect of, on timber . . . . 174
Angle of repose . . . . . . . . . 95
Annual rings in timber . . . . . . 149
Ants, white, destroy timber . . . . . 177
Arches, often improperly applied . . . 170
——— construction of timber . . . . 125
——— span of timber, limits of . . . 118
Arch-stones, pressure of, on centres . . 95
Ascent of bridges and roads . . . . . 119
Ash described . . . . . . . . . 200
——— experiments on the stiffness of . . 36
——————————— strength of . . 44
Aspen . . . . . . . . . . . . . 205

B.

PAGE

Bamberg, Bridge of . . . . . . . . 111
Barlow's experiments on detrusion . . 47
Barn floor, description of dry rot in . . 168
Basalt, specific gravity of . . . . . 234
Basilica of St. Paul, roof of . . . . . 85
Beams, equilibrium of an assemblage of 17
——— pressure of inclined . . . . . 13
——— stress upon horizontal . . . . 16
——— resistance of, to tension . . . 27
——— of the stiffness of, supported at both ends . . . . . . . . . . 31
——— strongest form of . . . . . 32
——— stiffest from a round tree . . . ib.
——— experiments on the stiffness of . 33
——— practical rules for the stiffness of 37
——— on the strength of . . . . . 42
——— experiments on the strength of . 44
——— strongest beam from a round tree 43
——— resistance to compression . . . 50
——— tie, rules for dimensions of . . 81
Beech described . . . . . . . . . 193
——— experiments on the stiffness of . 36
——————————— strength of . . 44
——— felled in summer least subject to worms . . . . . . . . . . . 153
Betula (see alder) . . . . . . . . 195
Binding joists, rules for the strength of . 67
——————— joints for . . . . . . 141
——————— table of scantlings for . . 220

PAGE
Binding joists to carry ceilings, table for 227
Birch, experiments on the stiffness of . 36
———————— strength of . 44
Boiling timber, remarks on . . . . . . 157
———— in alkaline solutions, remarks on . . . . . . . . . . . 174
Bolting on straps . . . . . . . . . 147
Bolts, sometimes used instead of straps . ib.
Bond, often improperly used . . . . 169
—— dangerous consequences of its decay ib.
Brass, specific gravity of . . . . . . 234
Braces, rules for strength of, for roofs . 84
——— joints proper for . . . . . . 146
——— for partitions, how most effectually applied . . . . . . . . . . . . 93
Brenta, bridge over the . . . . . . 106
Brick, specific gravity of . . . . . . 234
Brickwork, weight of a cubic foot of . 234
——— damp, a cause of dry rot . . 169
Bridge, curve of equilibrium for . . . 19
——— of centres for . . . . . . . 94
——— of wooden . . . . . . . . 106
——— of Sublicius . . . . . . . ib.
——— of Cæsar . . . . . . . . ib.
——— of Trajan . . . . . . . . ib.
——— of the middle ages . . . . . ib.
——— of Palladio . . . . . . . . ib.
——— across Portsmouth river in North America . . . . . . . . . . . 107
——— of Schaffhausen . . . . . . 108
——— of Freysingen . . . . . . . 109
——— of Bamberg . . . . . . . 111
——— of Ettringen . . . . . . . 112
——— of Mr. Burns, notice of . . . ib.
——— table of the principal dimensions of Mr. Wiebeking's . . . . . . . ib.
——— table of principal wooden, in Europe . . . . . . . . . . . . 113
——— of the design of . . . . . . ib.
——— of the width of . . . . . . 114
——— of the waterway for . . . . 115

PAGE
Bridge, of the span of . . . . . . 118
——— of the ascent of . . . . . . 119
——— of the rise of . . . . . 120, 131
——— of the abutments of . . . . . 122
——— of the piers of . . . . . . . 123
——— of the construction of the arches or frames of . . . . . . . . . 125
——— of the settlement of . . . . . 132
——— of the roadway and parapets of . ib.
——— of the scantlings of timbers for . 133
Bridging joists, of . . . . . . . . 68
———— table of scantlings for . 221
Building beams . . . . . . . . . . 140
——— strictures on a bad method of . 169
——— on timber, dangerous consequences of . . . . . . . . . . 170

## C.

Cæsar's bridge across the Rhine . . . 106
Cambering beams, remarks on . . . . 82
Carpenter's boast . . . . . . . . . 146
Carpentry defined . . . . . . . . . 1
Carvings, durability of . . . . . . 180
Cast iron, cohesive force of . . . . . 30
Cedar of Libanus described . . . . . 208
—— experiments on the stiffness of . . 36
———————— strength of . . 44
Cedar, red, described . . . . . . . 217
Ceiling joists, rules for . . . . . . 68
———— table of scantlings for . . 222
Ceilings, precautions required to form good . . . . . . . . . . . . 63
Cement, specific gravity of . . . . . 234
——— secures walls from damp . . . 171
Centre of gravity, how to find the . . . 12
Centres for bridges . . . . . . . . 94
——— pressure of the arch-stones on . 95
——— on designing . . . . . . . 98
——— of Conon Bridge . . . . . . 99

PAGE

Centres of Coldstream Bridge . . . . 99
——— of Neuilly Bridge . . . . . ib.
——— of Waterloo Bridge . . . . . 100
——— designs for . . . . . . . . ib.
——— on construction of . . . . . 101
——— on removing . . . . . . . . ib.
——— on computing the strength of . 102
Chalk, specific gravity of . . . . . 234
Changes of form in framing dangerous . 5
Charcoal, quantity of in different woods . 182
——— not a satisfactory criterion of durability . . . . . . . . . . . ib.
Charring wood, on . . . . . . . 159, 175
Cherry tree, experiments on the stiffness of 36
Chesnut described . . . . . . . . . 198
——— experiments on . . . . . . 199
——— the stiffness of . 36
——— the strength of 44
Christiana deal . . . . . . . . . . 212
Church roof . . . . . . . . . . . 78
Classification of woods, on the . . . . 183
——— table of . . . . 185
Clay, specific weight of . . . . . . 234
Coal tar, effect of, in dry rot, &c. . 175, 177
Cocking a tie beam on the wall plate . . 81
Cohesive force of woods . . . . 29, 231
——— of iron . . . . . . . . 30
——— defined . . . . . . . 185
Coldstream Bridge, centre of . . . . 99
Collar beam, joint for . . . . . . . 146
Columns, on the resistance of . . . . 48
——— bent . . 49
——— strongest form of . . . . . 50
——— practical rules for strength of . 55
Composition of forces, on the . . . . 3
Compression, on the resistance to . . . 47
——— experiments on . . . . 51
——— perpendicular to the fibres . . . . . . . . . . 60
Conon Bridge, centre of . . . . . . 99
Construction of floors . . . . . . . 61
Construction of roofs . . . . . . . . 72
——— of domes . . . . . . . . 88
——— of partitions . . . . . 91
——— of centres . . . . . . 94
——— of bridges . . . . . . 106
——— of scarfs and joints . . . 136
——— of timber arches for bridges 125
Copper, weight of covering of . . . . 74
——— used to prevent damp . . . . 171
Copperas, effect of, in preventing decay . 173
Corrosive sublimate a remedy against rot 174
Couples. See principal rafters.
Cranes, on the construction of . . . . 8
Crown posts. See king posts.
Crushing, on the resistance to . . . . 58
——— experiments on . . . . . ib.
Cubic parabola, method of describing . 20
Cupola, curve of equilibrium for . . . 22
——— on the construction of . . . . 88
Curb roofs, remarks on . . . . . . 73
Curb, failure of a timber . . . . . . 170
Curved ribs, roof with . . . . . . . 75
——— tables of scantlings for 225, 226
——— strength of . . . . . . 56
——— radius of curvature of . . 120
——— depth of beams for . . . 130
Curve of equilibrium, on the . . . . 19
——— for domes . . . . 22
Cylinders, rules for stiffness of . . . . 39
——— for strength of . . . . 45
——— hollow, strength of . . . . 43

## D.

Damp walls, to prevent . . . . . . 170
——— a cause of decay . . . . 171
Deal red (see fir) . . . . . . . . 209
——— white (see fir) . . . . . . . 212
Decay of timber, on the . . . . . . . 164
——— from continued dryness ib.

PAGE

Decay of timber from continued wetness 164
——— from alternate dryness and moisture . . . . . . . . . . 165
——— from moisture with heat . . . . . . . . . . . 165, 169
——— internal . . . . . 167
——— progress of . . . . ib.
——— prevented by wetness . 169
——— stoves sometimes a cause of . . . . . . . . . . . ib.
——— of the prevention of . 171
Decomposition of timber . . . . . . . 165
Deflexion, quantity allowed for, in the rules . . . . . . . . . . . . . . 36
Designing framing, on . . . . . . . 24
Detrusion, on . . . . . . . . . . . 46
——— experiments on . . . . . . 47
Direction of pressures, how determined 3
Dock roof, remarks on . . . . . . . 18
Dome, curve of equilibrium for . . . 22
——— on the construction of . . . . 88
——— scantlings for . . . . . . . . 89
——— failure of a . . . . . . . . . 170
Dovetail joints, on . . . . . . . 136, 146
Drains, precautions respecting . . . . 171
Dry, in seasoning, defined . . . . . 162
Dry rot, on . . . . . . . . . . . . 167
——— on repairing buildings affected with . . . . . . . . . . . . . 174
Drying buildings, on the good effects of . . . . . . . . . . . . . . . 172
Duhamel's experiments on the stiffness of oak beams . . . . . . . . . . 33
Durability of wood in salt mines . . . 173
——— examples of . . . 178
——— in piles . . . . . ib.
——— buried in the ground 179
——— of framed timbers . . . . 180
——— of old timber, causes of . . . 181
——— of woods exposed to the weather, experiments on . . . . . . 182

PAGE

Durability of different kinds of wood . . 181
Dutch method of preserving timber . . 175

E.

Earth, a cause of damp . . . . . . . 171
——— specific weight of . . . . . 234
Elasticity of timber, on the . . . . . 185
——— on the modulus of . . . . ib.
Ellipse to describe on a large scale . . 14
Elm, kinds of, described . . . . . . 201
——— experiments on the stiffness of . . 36
——— strength of . . 44
Equilibrium of an assemblage of beams . 17
——— curve of . . . . . . . . 19
——— for domes . . . . 22
Ettringen Bridge . . . . . . . . . 112
Experiments on the cohesive force of woods . . . . . . . . . . . . 29
——— on the lateral cohesion . . ib.
——— on the stiffness of beams . 33
——— on the strength of beams . 44
——— on the compression of beams 51
——— remarks on making . . . 54
——— on the resistance to crushing 58
——— on the resistance to compression at the joints . . . . . . . . . 60
——— on the strength of floors . . 61

F.

Fagus. See beech, and chesnut
Fall of water under a bridge, to determine . . . . . . . . . . . . . 117
Felling timber, on . . . . . . . . . 152
——— when trees are of a proper age for 153
——— on the proper season of the year for . . . . . . . . . . . . . ib.
Fir, red or yellow, described . . . . 209

PAGE
Fir, white or spruce, described . . . . 212
— experiments on the stiffness of . . . 35
—— strength of . . . 44
—— resistance of to compression . . . . . . . . . 58, 60
Fishing a beam . . . . . . . . . . 137
Flexure, the resistance to, of most importance . . . . . . . . . . . 22
Floating timber in docks and rivers a cause of decay . . . . . . . . . 169
Flooring, naked, described . . . . . 61
—— single joisted, on . 61, 62
—— double, on . . . . . 61
—— framed, on . . . 61, 63
—— experiments on the strength of . . . . . . . . . 61
Floors, general remarks on . . . . . 69
—— Serlio's of short timbers . . . 70
—— curious one at Amsterdam . . . 71
—— ground most subject to decay . 171
—— means of securing from dry rot . . . . . . . . . . . . 172
Forces, experiment to show the action of 4
—— their effects, how to measure . . 4
—— composition and resolution of 3, 10
—— parallelogram of . . . . . . 10
—— polygon of . . . . . . . . 11
Fracture, on the points of, in a system of framing . . . . . . . . . . . . 17
Framing, to measure the strains in . . 6
—— to distinguish ties from struts in 9
—— points of fracture in a system of 17
—— curve of equilibrium in a system of . . . . . . . . . . . . 19
—— on designing . . . . . . . 24
—— on the strength of joints for . . 60
—— for spanning a wide opening . . 125
—— on the joints of . . . . . . 141
Framed floors, on . . . . . . . . 61, 63
Fraxinus (see ash) . . . . . . . . . 200
Freysingen Bridge described . . . . . 109

PAGE
Friction of stones, on . . . . . . . . 95
Fungus, a product of decayed timber . . 168
—— not destroyed by a slow current of air . . . . . . . . . . . . . 172

G.

Gates, painting of, sometimes a cause of decay . . . . . . . . . . . . 170
Geometry essential to carpentry . . . 1
Girard's experiments on the resistance of beams to compression . . . . . . . 52
Girders, on, with rules for dimensions of 63
—— on reversing and bolting . . . 64
—— trussed, remarks on . . . . . ib.
—— Mr. Barlow's experiments on . . . . . . . . . . . . . 65
—— on forming for long bearings . 66
—— remarks on laying . . . . . 69
—— table of scantlings for . . . . 219
Gothic builders particular in the choice of timber . . . . . . . . . . . 188
—— roofs, on . . . . . . . . 72, 79
Granites, specific gravity of . . . . . 234
Gravity, centre of, how to find . . . . 12
—— specific, table of, for woods . . 232
—— for various materials . . . . . . . . . . . 234
—— remarks on determining 236
Green copperas, a preventive of decay . 173
Ground joists, on scantlings of . . . . 68
—— floors, to secure from decay 68, 172

H.

Hardness of woods, &c. on the . . . . 186
Heart-wood, formation and nature of . 151
Heat, a cause of dry rot when moisture is present . . . . . . . . . . . . 165

PAGE

Honduras mahogany described . . . . 205
———— experiments on 36, 44
Horizontal thrust of a roof, &c. how to measure . . . . . . . . . . 14
Horse chesnut, experiments on the stiffness of . . . . . . . . . . . . 36
Houses, strictures on the London method of building . . . . . . . . . 170

## I, J.

Ice-breakers . . . . . . . . . . . . 124
Jib of a crane . . . . . . . . . . 8
Inclined beams, pressure of . . . . . 13
———— stiffness of . . . . . 38
Indian oak (see teak) . . . . . . . . 206
Insects, to preserve timber from . . . 176
Internal decay, example of . . . . . 167
Joints, pressures upon, how to estimate . 11
——— strength of . . . . 47, 60, 138
——— method of securing against decay 110
——— on the construction of . . . . 136
——— to resist tension, on . . . . . 137
——— to resist cross strains, on . . . 139
——— to resist compression, on . . . 141
——— of framing, on . . . . . . 142
——— for ties and braces, on . . . . 146
——— on dovetail . . . . . . 136, 146
Joists, common, rules for . . . . . 62
——— binding, rules for . . . . . . 67
——— bridging, on . . . . . . . . 68
——— ground, on . . . . . . . . . ib.
——— ceiling, on, with rules . . . . ib.
——— common, table of scantlings for 221
——— binding, for floors, table of scantlings for . . . . . . . . . . . 220
——— binding, for ceilings, table of scantlings for . . . . . . . . . . 227
——— bridging, table of scantlings for 221
——— ceiling, table of scantlings for . 222

PAGE

Iron, cohesive force of . . . . . . . 30
—— to preserve from rust . . . . . 147
—— straps, on . . . . . . . . . . 146
—— sulphate of, effect of, in preventing dry rot . . . . . . . . . . . . 173
—— specific gravity of . . . . . . 234
Juglans (see walnut) . . . . . . . 205
Juniperus (see cedar) . . . . . . . 217

## K.

Keys for scarfs . . . . . . . . . . 137
King posts, on, with rules for . . . . 79
———— straps for . . . . . . . . 147
Knots, the strained side of a beam should be free from . . . . . . . . . . 16

## L.

Lamandé's experiments on the resistance of beams to compression . . . . . 51
Lantern of a dome . . . . . . . . . 88
Larch described . . . . . . . . . 215
—— experiments on the stiffness of . . 35
———————— strength of . . 44
—— American black . . . . . . . 216
———— red . . . . . . . . . ib.
Layers, annual, on . . . . . . . . 149
Lead covering, weight of . . . . . . 74
—— sometimes put in joints . . . . 145
—— used to prevent damp rising in walls . . . . . . . . . . . . 171
Levers, on framed . . . . . . . . 6
——— strains in framed, the same as in a solid beam . . . . . . . . . . 7
Lime, quick, a cause of decay . . . . 166
———— preserves timber from worms 176
—— tree, experiments on the stiffness of 36
Loam, used formerly for bedding girders, &c. . . . . . . . . . . . . 169

PAGE
Locust tree (see acacia) . . . . . . . 203
London Bridge, fall of water under . . 117
——— durability of the piles of . 179

## M.

Mahogany, kinds of, described . . . . 204
——— experiments on the stiffness of 36
——— strength of 44
Maple, experiments on the stiffness of . 36
Mar Forest timber . . . . . . . . . 210
Mechanics, a knowledge of, essential in carpentry . . . . . . . . . . 1
Middle ages, bridges of . . . . . . 106
Modulus of elasticity, on the . . . . 185
Moisture the chief cause of decay . . . 165
Mortar, a cause of rotteness . . . . . 169
——— specific gravity of . . . . . 235
Moscow, roof of Riding House at . . . 87

## N.

Nails, how secured from rust by slaters . 148
Naked flooring, on . . . . . . . . . 61
——— rules for dimensions of timbers of . . . . . . . . . . 62
——— general observations on . 69
——— of short timbers . . . 70
Neuilly Bridge, centre of . . . . . . 99
Norway spruce . . . . . . . . . . 212
——— timber . . . . . . . . . 211

## O.

Oak, kinds of, described . . . . . . 188
—— experiments on the stiffness of . 33, 34
——— strength of . . 44
——— strength of posts 51
PAGE
Oak, experiments on the resistance of, to compression . . . . . . . . 58, 60
——— English species 190
—— Durmast . . . . . . . . . 191
—— American species of . . . . . ib.
—— properties of different kinds of . . 192
Oblique pressures, how measured . . . 11
Odoriferous woods most durable . . . 181
Oil and tar, composition of, to preserve timber . . . . . . . . . . . 175
— useful as a preventive of worms . . 176
Oxycedrus (see cedar, red) . . . . . 217

## P.

Paint, effect of, on unseasoned wood 166, 170
—— rendered more durable by sanding it 175
Painted floorcloth a cause of decay . . 171
Palladio, bridges of . . . . . . . . 106
Parabola, the curve of equilibrium for an uniform load . . . . . . . . . 20
——— cubic, how to describe . . . . 21
——— the curve for a dome uniformly loaded . . . . . . . . . 22
——— common, strongest form for a column . . . . . . . . . . . 50
——— how to describe . . . 76
Parallelogram of forces, on the . . . . 10
Parapets of bridges, on the . . . . . 133
Partitions, on the construction of . . . 91
——— weight of a square of . . . 92
——— description of designs for . . 93
Pear tree, experiments on the stiffness of 36
Pediments, angle of . . . . . . . 78
Pencil, cedar . . . . . . . . . . 217
Piers of bridges, on . . . . . . . 123
——— Mr. Telford's method of forming . . . . . . . . . . . 124
Piles and pile planks . . . . . . . 125
—— durability of . . . . . . . . 179
Pinaster, on the . . . . . . . . . 214

PAGE

Pine (see red fir) . . . . . . . . . 209
—— experiments on the stiffness of . . 35
—————————— strength of . . 44
—— pitch, on the . . . . . . . . . 214
—— American, on the . . . . . . ib.
—— Scotch, on the . . . . . . . 209
—— yellow, on the . . . . . . . 214
Pins, a good method of connecting timbers . . . . . . . . . . . . 146
Pipe-worm, on the . . . . . . . . 176
Pitch of a roof . . . . . . . . . 73
—— effect of, in seasoned wood . . . 166
—— pine, on the . . . . . . . . 214
Plane tree described . . . . . . . 196
———— experiments on the stiffness of 36
————————————— strength of 44
Platanus (see plane tree) . . . . . . 196
Polygon of forces, on the . . . . . 11
Poplar, kinds of, described . . . . . 207
——— experiments on the stiffness of . 36
———————————— strength of . 44
Populus (see poplar) . . . . . . . 207
Position of beams, effect of the . . . . 5, 7
Posts, stiffness of . . . . . . . . 48
—— experiments on . . . . . . . 51
—— practical rules for scantlings of . . 55
—— story, tables of scantlings for . . 229
Practical rules for the stiffness of beams . 37
——————————— strength of beams 45
———————— for columns, posts, &c. . 55
Preservation of straps, on the . . . . 147
—————— of timber, on the . . . . 171
Pressure of beams, how to calculate . . 3
——— direction of, how found . . . 4
Pressures in framing, how to measure . 5, 6
Principal rafters of a roof, on the . . . 82
—————— joints for . . . . . . 143
—————— straps for . . . . . . 147
Properties of woods . . . . . . . 185
———————— table of . . . . . 131
Purlins for roofs, rules for . . . . . 84

PAGE

Purlins, table of scantlings for . . . . 227
Pyrites, a good material to prevent decay 173

Q.

Queen posts, rules for . . . . . . . 80
————— straps for . . . . . . . 147
Quicklime a cause of decay . . . . . 166
Quassia, infusion of, used to preserve wood from worms . . . . . . . . . 196
Quercus (see oak) . . . . . . . . 188
——— robur described . . . . . . ib.
——— sessiliflora . . . . . . . . 181

R.

Radius of curvature for bridges . . . 120
Rafters, principal, rules for . . . . . 82
—————— joints for . . . . . 143
—————— straps for . . . . . 147
——— common, rules for . . . . . 85
—————— tables of scantlings for 228
Railing for bridges, on . . . . . . 133
Red fir described . . . . . . . . 209
Rennie's experiments on the resistance to crushing . . . . . . . . . . . 58
Removing centres, on . . . . . . 101
Repairs after dry rot, on . . . . . . 174
Resilience of timber, on the . . . . . 237
Resistance of timber, on the . . . . 25
———— to flexure the most important ib.
———— to tension . . . . . . . 27
———— to cross strains . . . . . 30
———— to compression . . . . . 47
———— of columns and posts . . . 48
———— to crushing . . . . . . . 58
———— of joints . . . . . . . . 60
Resolution of forces, on the . . . . . 3
Resultant of a system of forces, to determine . . . . . . . . . . . . 10

PAGE
Ribs, curved, strength of . . . . . . 56
——— roof with . . . . . . 75
Riga oak . . . . . . . . . . . . 191
—— fir . . . . . . . . . . . . 210
Rings, annual, on . . . . . . . . . 149
Rise of wooden arches . . . . . . 132
Rivers, on the firmness of the beds of . 116
——— velocity of . . . . . . . . 118
Roadway of bridges, on the.. . . . . 132
Road scrapings a cause of dry rot . . . 169
Robinia (see acacia) . . . . . . . 203
Robison, Professor, his experiments on detrusion . . . . . . . . . . 46
Roman tiling . . . . . . . . . . 86
Rondelet's experiments on crushing . . 58
Roof, strains in a truss for, how measured 6
—— to find the horizontal thrust of . . 14
—— shed, on the pressure of . . . . 15
—— dock, remarks on . . . . . . 18
—— on the construction of . . . . . 72
—— on Gothic . . . . . . . . 72, 79
—— on the pitch of . . . . . . . 74
—— description of, for various spans . ib.
—— with curved ribs . . . . . . . 75
—— without a tie beam, on . . . . . 78
—— of Westminster School . . . . 79
—— of the Basilica of St. Paul, at Rome 85
—— of the Theatre d'Argentina at Rome 86
—— of the Riding House at Moscow . 87
—— of the Royal Military Chapel at Woolwich . . . . . . . . . . 226
—— tables of scantlings for . . 223—226

S.

Salt, effect of, in preventing dry rot . . 173
Sand, specific gravity of . . . . . . 235
Sanded painting more durable than common . . . . . . . . . . . . . 175
Sap, on the motion of . . . . . . . 149

PAGE
Sap, on the nature of . . . . . . . . 150
—— confined, a cause of dry rot . . . 166
—— wood, on the nature of . . . . 150
———— proportion of, in trees . . 151
Sawing, result of an experiment on . . 186
Sawn timber neither so strong nor so durable as split . . . . . . . . 183
Scantlings, various tables of . . . . . 219
Scarfing, on . . . . . . . . . . . 137
Schaffhausen Bridge . . . . . . . 108
Scorching timber, remarks on . . . . 159
Scotch pine . . . . . . . . . . . 209
Seasoning timber, on . . . . . . . . 155
——— water, on . . . . . . . . 156
——— timber, Duhamel's experiments on . . . . . . . . . . . . . 159
———— Couch's experiments on 160
———— Wiebeking's experiments on . . . . . . . . . . . . . 161
———— Bishop Watson's experiments on . . . . . . . . . . ib.
——— on the laws of . . . . . . . ib.
——— is the best method of preserving timber . . . . . . . . . . . . 171
——— in the frame not to be recommended . . . . . . . . . . . . 172
Seasoned, term limited . . . . . . 162
Sea water, effect of, in preventing decay 173
Septa of woods, on the . . . . . . 184
Serlio's floors of short timbers . . . . 70
Settlement, quantity of, allowed for in the rules . . . . . . . . . . . . . 36
——— of bridges . . . . . . . . 132
——— unequal, effect of . . . . . 69, 91
Shed roofing, pressure of . . . . . . . 15
Ship-worm, to prevent the ravages of . . 176
Shrinkage of timber, effect of . . . . . 136
Silver grain, on the . . . . . . . . . 184
—— fir . . . . . . . . . . . . 214
Single joisted floors, on . . . . . . . 61
———— table of scantlings for 221

PAGE

Slates used to prevent damp walls . . . 171
—— on the specific gravity of . . . . 235
Slating, pitch for, and weight of . . . 74
Spanish chesnut (see chesnut) . . . . 198
—— mahogany described . . . . 205
Spars. See rafters
Specific gravity of woods, table of . . 232
—— various materials, table of . . . . . . . . . . . . 234
Spruce fir, described . . . . . . . 212
Spur of a crane . . . . . . . . . 8
Stability from position . . . . . . 2
—— from equal resistance . . . . ib.
Steaming timber, on . . . . . . . . 157
Stiffness defined . . . . . . . . . 27, 30
—— knowledge of, most important in carpentry . . . . . . . . . . 27
—— distinguished from strength . . ib.
—— to resist tension, on . . . . . 27
—— to resist cross strains . . . . 30
—— experiments on . . . . . . 34
—— remarks on . . . . . . . . 186
—— comparative, of woods, table of . 231
Stones, specific gravity of various 235, 236
Stonework, weight of a cubic foot of . . 236
Story posts, tables of scantlings for 229, 230
Stoves, a cause of decay . . . . . . 169
Strains in framing, how measured . . . 6
—— on beams laid horizontally . . 16
Straining beams, on . . . . . . . . 83
Straps, on . . . . . . . . . . . 147
Strength defined . . . . . . . . . 27
—— distinguished from stiffness . . ib.
—— to resist tension . . . . . . 28
—— of iron . . . . . . . . . 30
—— to resist cross strains . . . . 42
—— experiments on . . . . . . 44
—— . . . . . . 46
—— of columns, posts, &c. . . . 48, 55
—— of curved ribs . . . . . . . 56
—— of joints . . . . . . . . . 60

PAGE

Structure of woods, on the . . . . . 183
Struts, how distinguished from ties . . 9
—— rules for . . . . . . . . . 84
Stucco, an excellent preventive of damp . 171
Sublimate, corrosive, a wash of, for dry rot . . . . . . . . . . . . . 174
Sulphate of copper, used to prevent dry rot ib.
—— of iron, ditto . . . . . 173, 174
Suspending pieces, on . . . . . 80, 145
—— straps for . . . . 147
Sweet chesnut (see chesnut) . . . . 198
Swietenia (see mahogany) . . . . . . 204
Sycamore described . . . . . . . . 197
—— experiments on the stiffness of 36
—— strength of 44

## T.

Table of the classes of woods . . . . 185
Tables of scantlings, &c. . . . . . . . 219
Tar, effect of, on unseasoned wood . . 166
—— coal, of use to preserve timber . . 175
Teak described . . . . . . . . . . 206
—— experiments on the stiffness of . . 36
—— strength of . . 44
Tectona (see teak) . . . . . . . . . 206
Templets . . . . . . . . . . . . . 69
Tension, on the resistance to . . . . 27
Texture, close, a cause of durability . . 183
Thatch, pitch for a roof of . . . . . 74
Theatre d'Argentina, roof of . . . . 86
Ties, how distinguished from struts . . 9
—— on the joints of . . . . . 137, 146
Tie beams, on . . . . . . . . . . 81
—— remarks on putting blocks under . . . . . . . . . . . . 82
—— on cambering . . . ib.
Tiles, pitch for and weight of . . . . 74
Timber, knowledge of its resisting power necessary . . . . . . . . . . 25

PAGE
Timber bridges, on . . . . . . . . . 106
——— principles of constructing . . . 125
——— nature of . . . . . . . . . 149
——— on felling . . . . . . . . . 152
——— on seasoning . . . . . . . . 155
——— on the decay of . . . . . . . 164
——— kinds of, most subject to decay . 168
——— should not be suffered to float in docks . . . . . . . . . . . . 169
——— should not be used for supporting heavy stonework . . . . . . . 170
——— on the prevention of decay of . 171
——— to preserve when exposed to the weather . . . . . . . . . . . 175
——————— from worms and insects . . . . . . . . . . . . . . 176
——— durability of, in different states . 178
——————— experiment on . . . 182
——— split more durable than sawn . . 183
——— properties of . . . . . . . . 186
——— table of the properties of . . . 231
——————— specific gravity of . 232
——— on the resilience of . . . . . 237
Time required to dry and season timber . 164
Toughness of woods . . . . . . . . 186
——————— table of the comparative . . . . . . . . . . . . . 231
Trajan's Bridge . . . . . . . . . . 106
——————— durability of the piles of 179
Trees, on felling . . . . . . . . . . 152
—— old, often decayed . . . . . . 166
—— rapidly grown, soon decay . . . 168
—— from close forests subject to decay . . . . . . . . . . . . . 168
Triangle of forces . . . . . . . . . 4
Trimmers described . . . . . . . . 62
Trimming joists, on the scantlings of . 63
Truss, to measure the strains in . . . 6
Trussed girders, remarks on . . . . . 64
Trussing, principles of . . . . . . . 125
Tubes, on the strength of . . . . . 43

PAGE

U, V.

Velocity of rivers, on the . . . . . . 118
Ventilation as a prevention of decay, on . 172
Ulmus (see elm) . . . . . . . . . 201

W.

Wall-plates, dimensions of . . . . . 69
Walls, to prevent moisture rising in . . 171
—— should be allowed time for drying . 172
Walnut tree described . . . . . . . 205
——————— experiments on the stiffness of . . . . . . . . . . . . . . 36
————————————— strength of . . . . . . . . . . . . . . 44
Water, presence of, essential to the decomposition of wood . . . . . . 165
Waterloo Bridge, centre of . . . . . 100
Water seasoning, on . . . . . . . . 156
Water-way under bridges, on the . . . 115
Washes, use of, in preventing dry rot . 174
Weather, to preserve wood exposed to . 175
Weight, effect of . . . . . . . . . 3
——— of timber in different states . . 159
——— of materials, table of . . . . 234
Wet rot . . . . . . . . . . . . . 167
Whale oil preserves timber from worms 177
White deal described . . . . . . . . 212
Width of bridges, on the . . . . . . 114
Wiebeking's table for rise of bridges . . 121
Willow, experiments on the stiffness of . 36
————————————— strength of . 44
Woods, on the cohesive force of . . . 29
——— experiments on the stiffness of 33—36
————————————— strength of . 44
——— properties of . . . . . . . . 149
——— structure of . . . . . . . . ib.
——— on the decay of . . . . . . . 164

PAGE
Woods, on the preservation of . . . . 175
——— from worms . 176
——— on the durability of . . . . . 178
——— experiment on the durability of . 182
——— on the structure and classification of . . . . . . . . . . . . . 183
——— table of the properties of . . . 231
——— of the specific gravities of . . 232
Wooden bridges, on . . . . . . . . 106
——— on the principles of constructing . . . . . . . . . . . 125

PAGE
Woody fibre . . . . . . . . . 151, 165
Worms, to preserve wood from . . . 176
——— ship . . . . . . . . . . . ib.

Y.

Yellow fir described . . . . . . . . 209
——— pine . . . . . . . . . . . . 214
Young, Dr. Thomas, his formula for the resistance of columns . . . . . . 53

THE END.

# ERRATA.

Page 4, line 4 from the top, *for* Ac *read* AC.
—— 4, — 14 ———— *for* and *c* *read* and C.
—— 8, — 26 ———— *for* CA *read* Ca.
—— 10, — 4 ———— *for* directions *read* direction.
—— 20, — 5 ———— *for* 2Bc *read* 2BC.
—— 35, — 4 from the bottom, *for* 03 *read* 103.
—— 39, — 4 ———— *for* 17*a* *read* 1·7*a*.
—— 47, — 10 from the top, *for* Ac *read* AC.
—— 49, — 11 ———— *for* *c* *read* C.
—— 63, — 4 from the bottom, *for* depth *read* breadth.
—— 64, top line, *for* breadth *read* depth.
—— 104, line 7 from the bottom, *for* *eb* *read* *eh*.
—— 116, in the table, *for* 10 inches diameter *read* one inch diameter.
—— 203, line 8 from the top, *for* and Annals *read* in the Annals.
—— 209, — 15 ———— *for* larger perceptible *read* perceptible larger.
—— 224, — 9 from the bottom, *for* $5 \times 3\frac{1}{4}$ *read* $5 \times 3\frac{1}{7}$.

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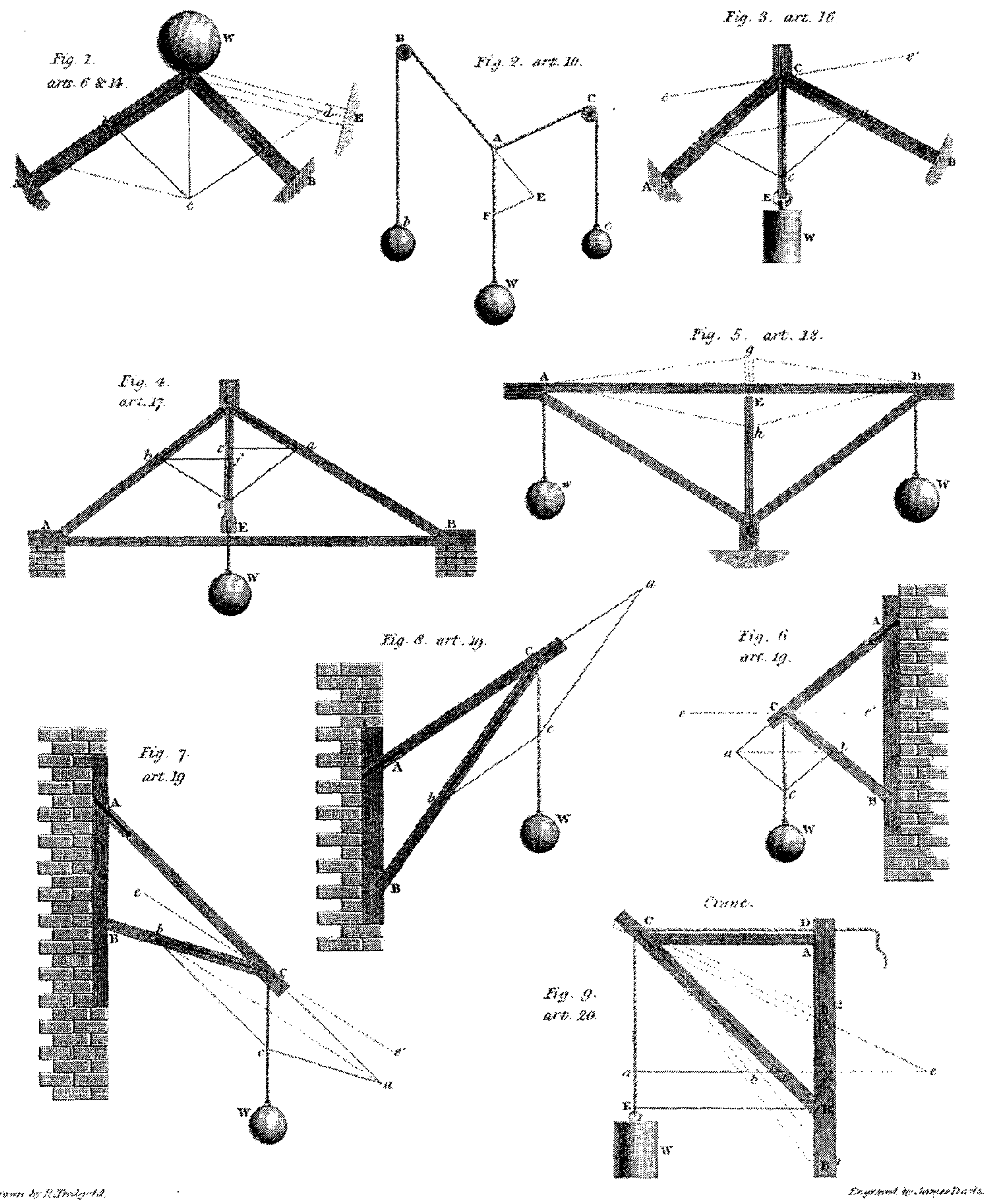


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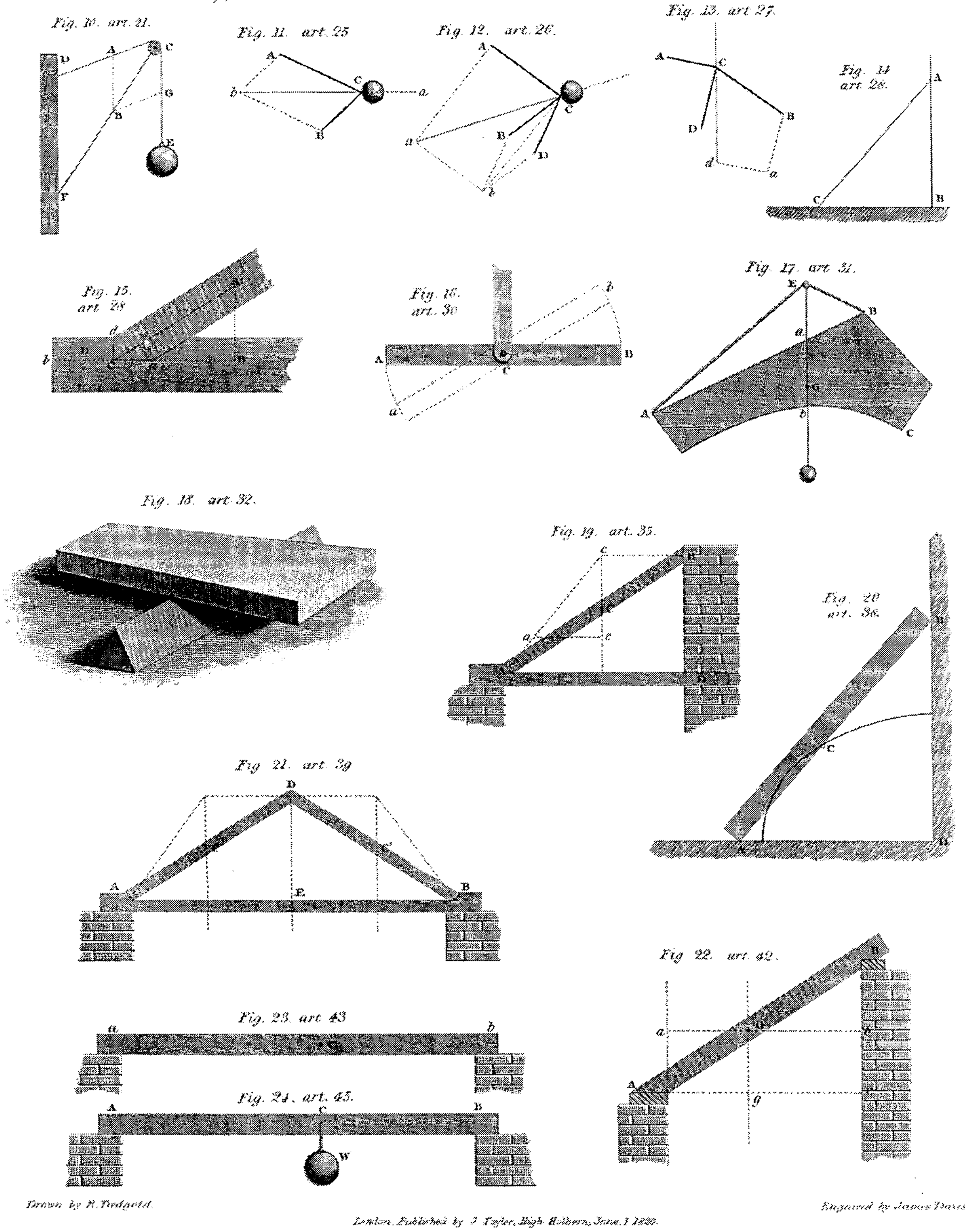
Pressure of Beams and Centre of Gravity. PLATE II.

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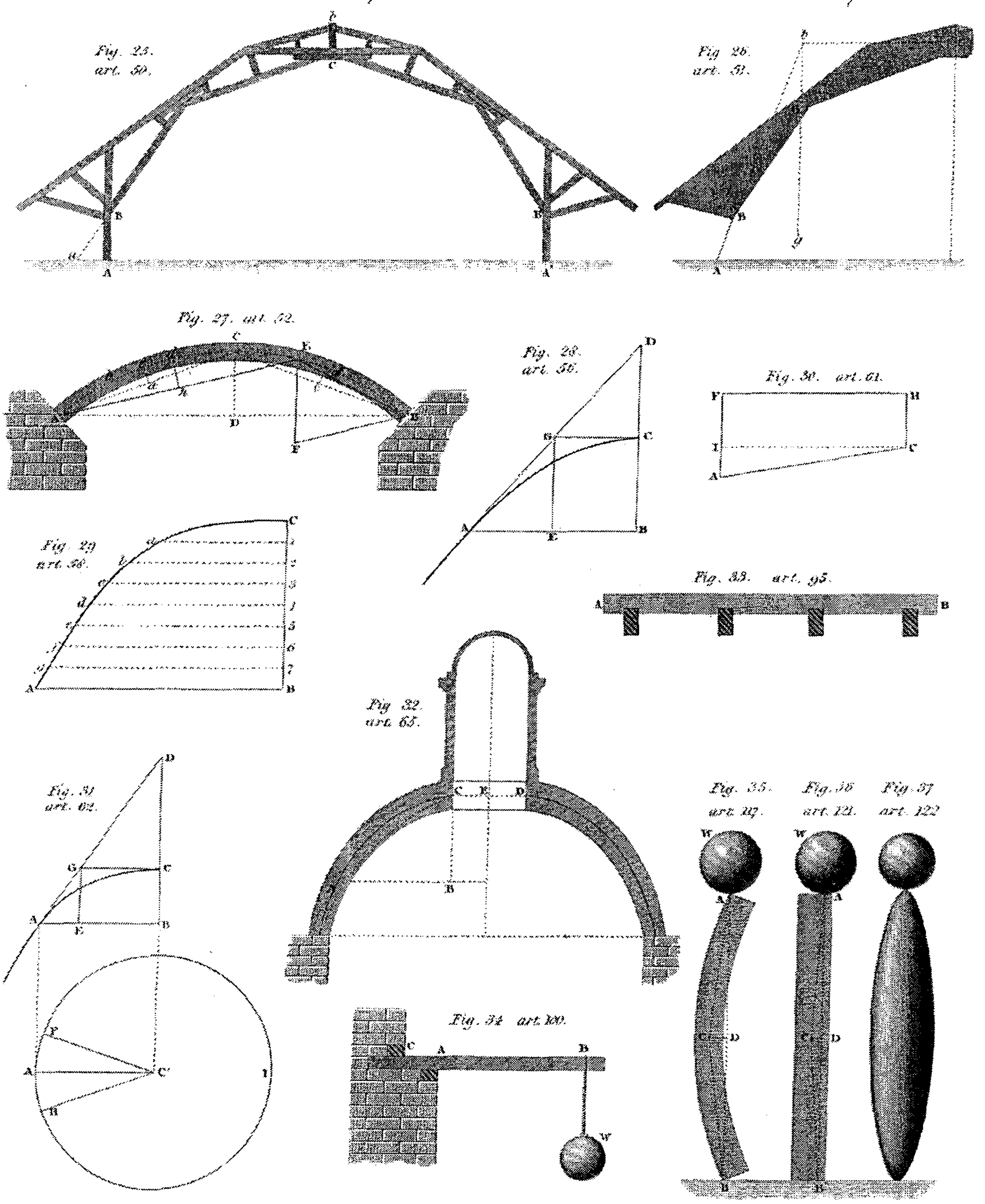
*Equilibrium and Pressure of Beams and Framing.* PLATE III.

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# Naked Flooring.

PLATE IV.

Fig. 38. art. 133.

Fig. 39. art. 133.

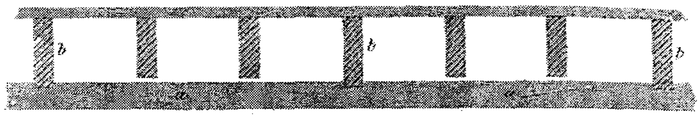


Fig. 40. art. 134.

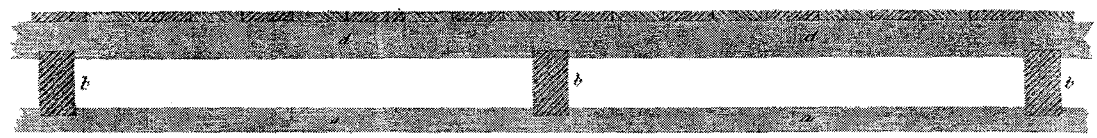


Fig. 41. art. 135.

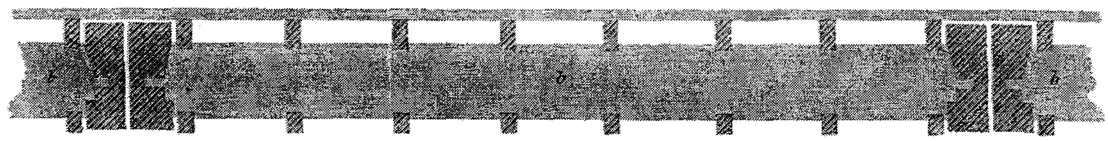


Fig. 42. art. 143.

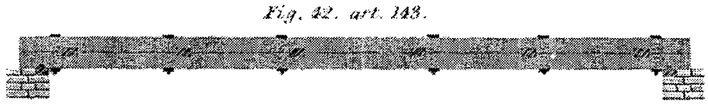


Fig. 43. art. 144.

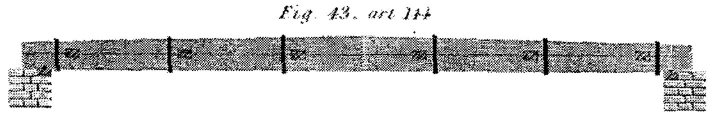


Fig. 44. art. 145.

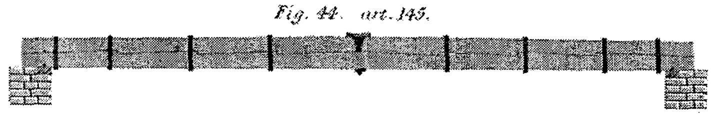


Fig. 46. art. 151.

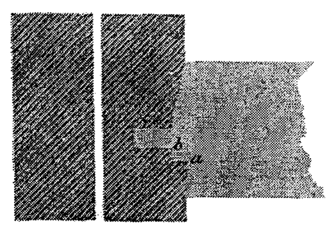


Fig. 45. art. 147.

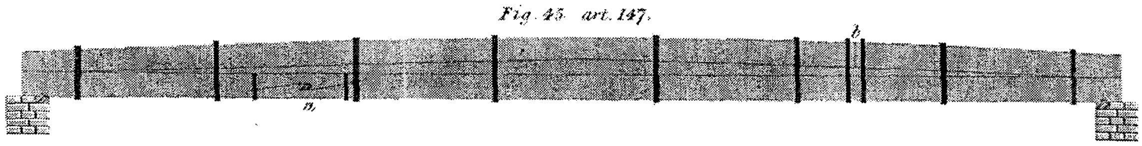


Fig. 47. art. 159.

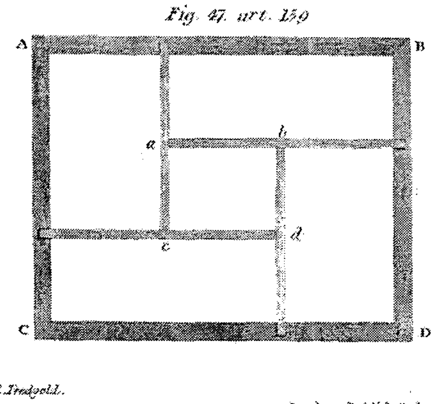
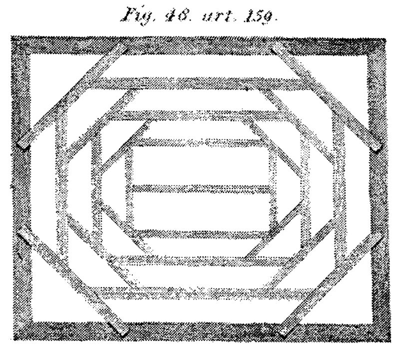



Fig. 48. art. 159.



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# Roofs.



Fig. 49. art. 164.

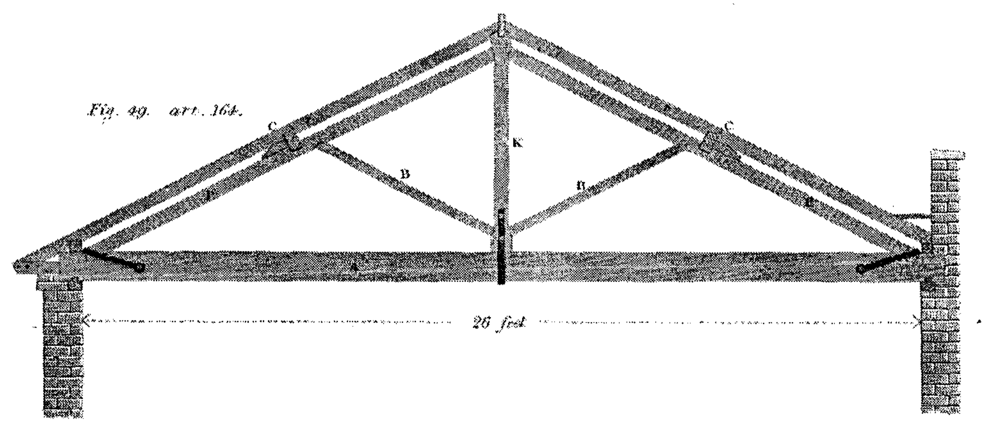
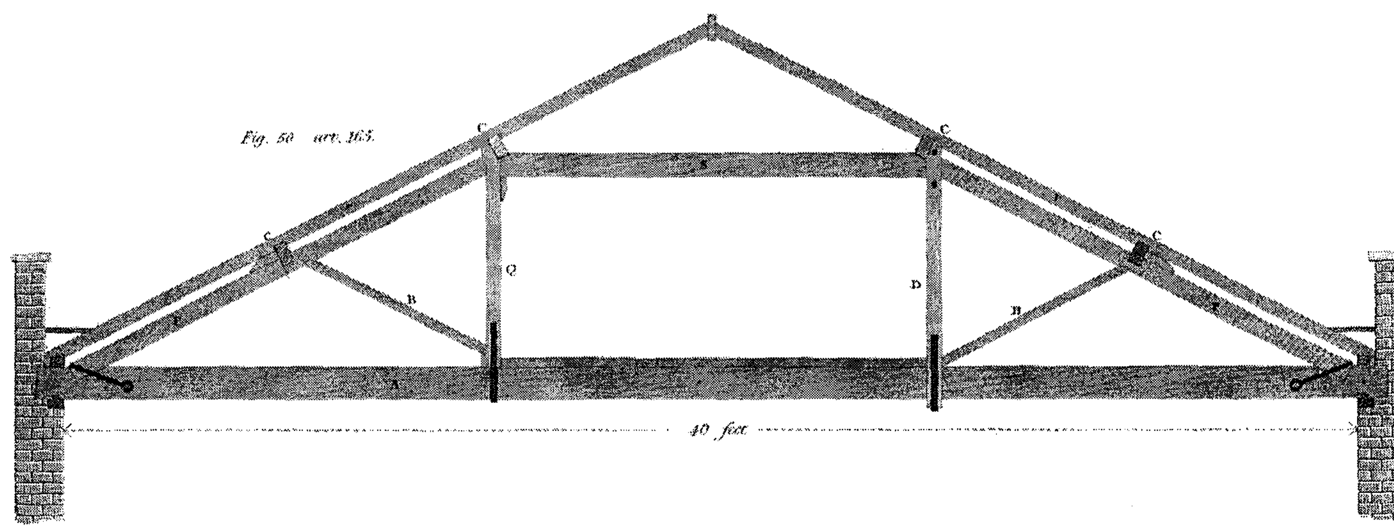



Fig. 50. art. 165.

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# Roofs.

PLATE VI.

Fig. 51. art. 166

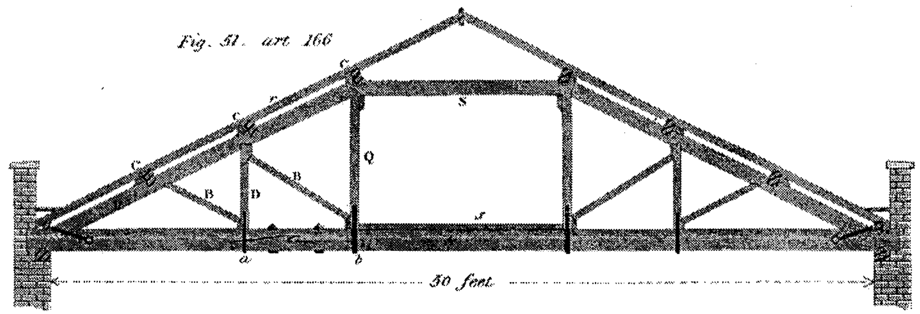
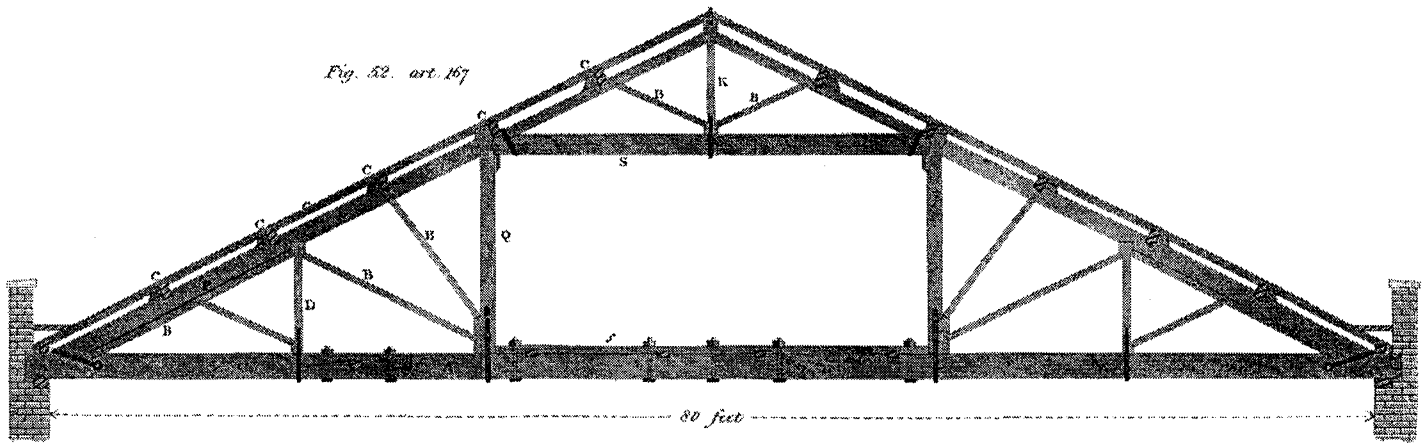



Fig. 52. art. 167

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# Roofs.



Fig. 53 art. 169.

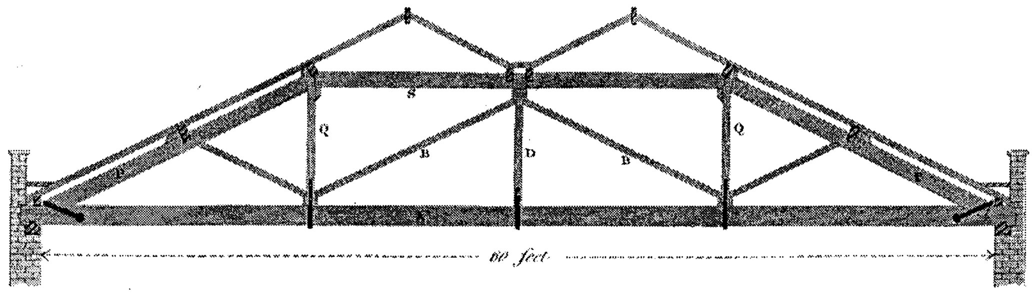
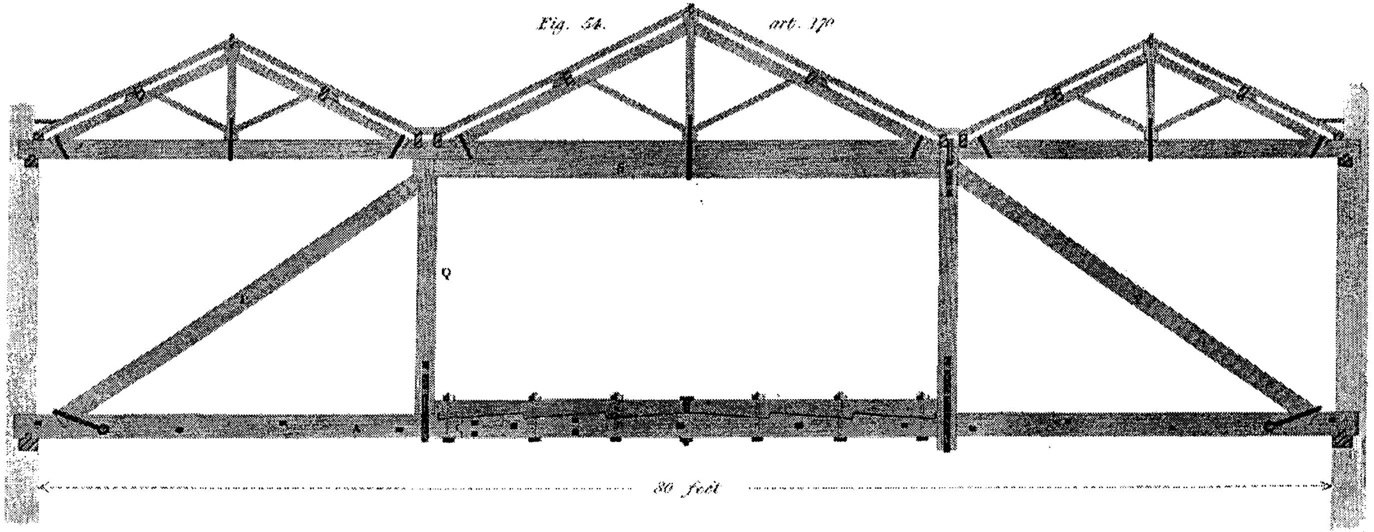



Fig. 54. art. 170

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# Roofs.

PLATE VIII.

Fig. 55. art. 171.

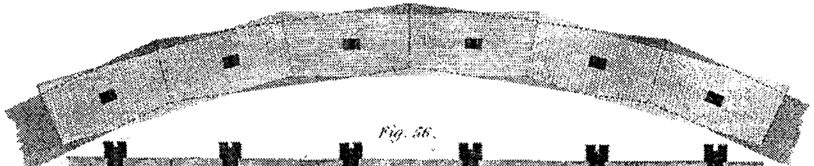


Fig. 56.

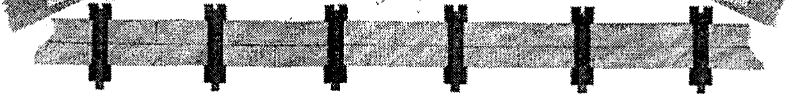


Fig. 59. art. 171.

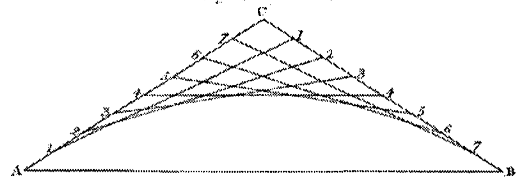



Fig. 58.

Fig. 57. art. 171.

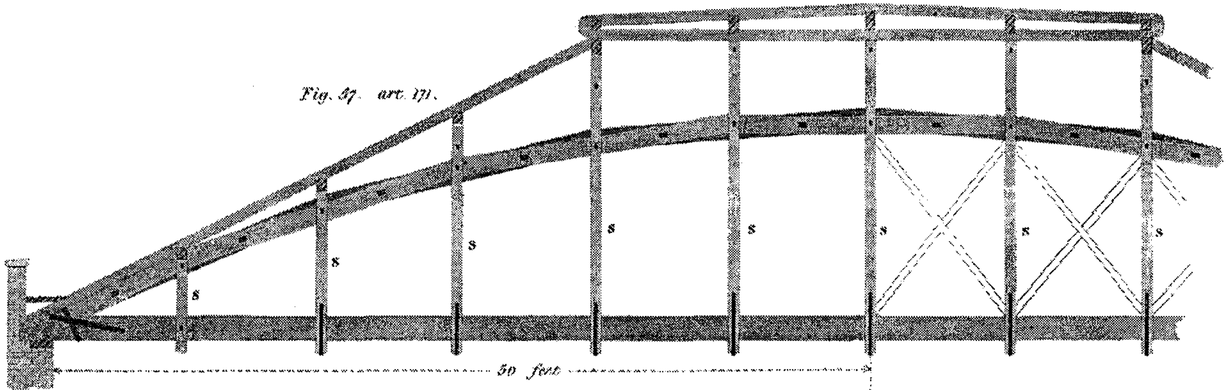
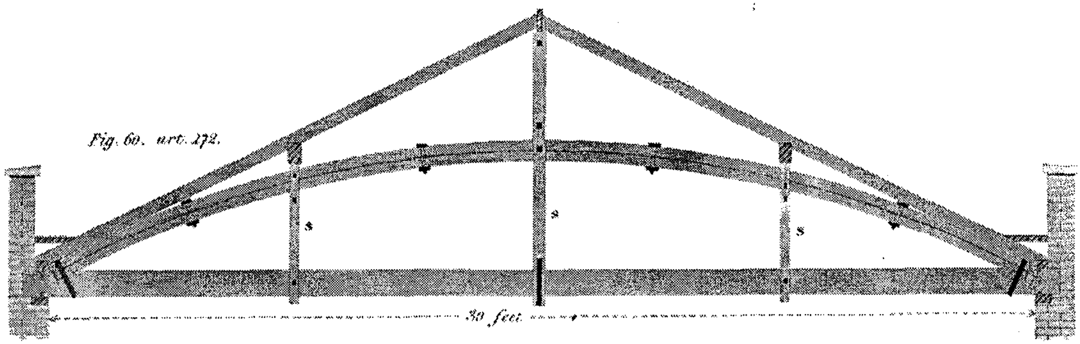



Fig. 60. art. 172.

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# Roofs.

PLATE . IX.

Fig. 61. art. 173.

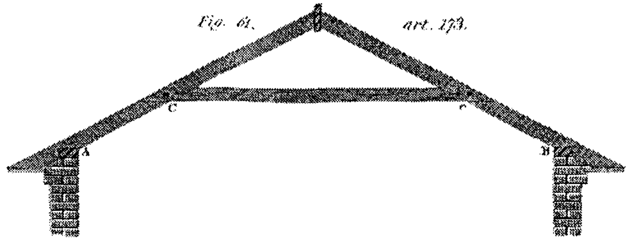


Fig. 62. art. 174.

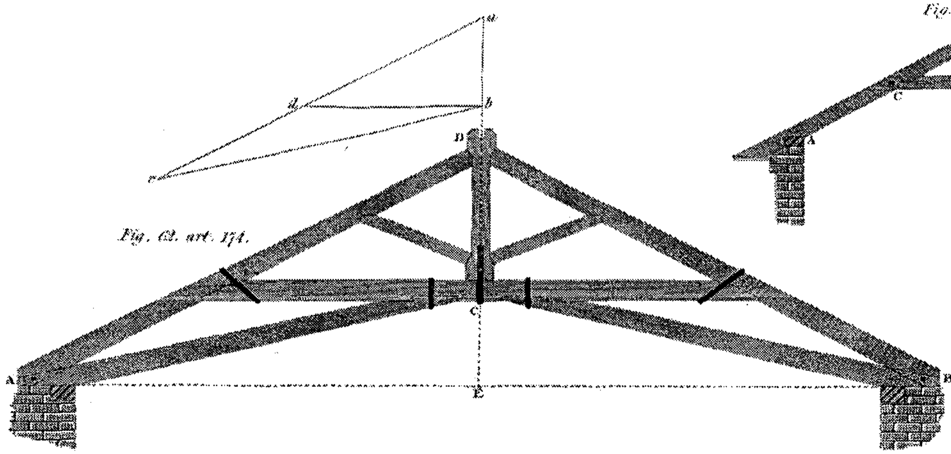


Fig. 65. art. 183.

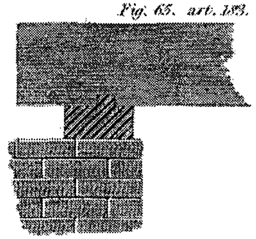


Fig. 64. art. 175.

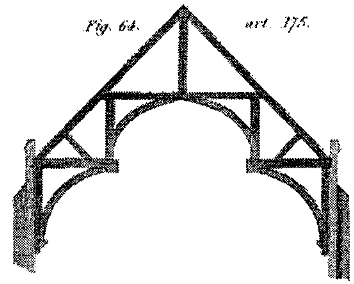
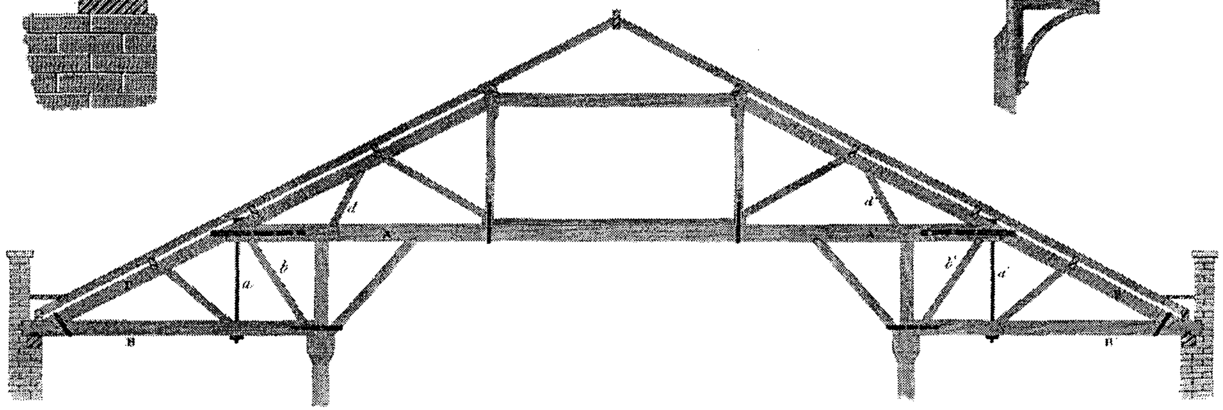


Fig. 63. art. 175.



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# *Roofs that have been executed.*



Roof of the Basilica of St. Paul at Rome
Fig. 66. art. 192.

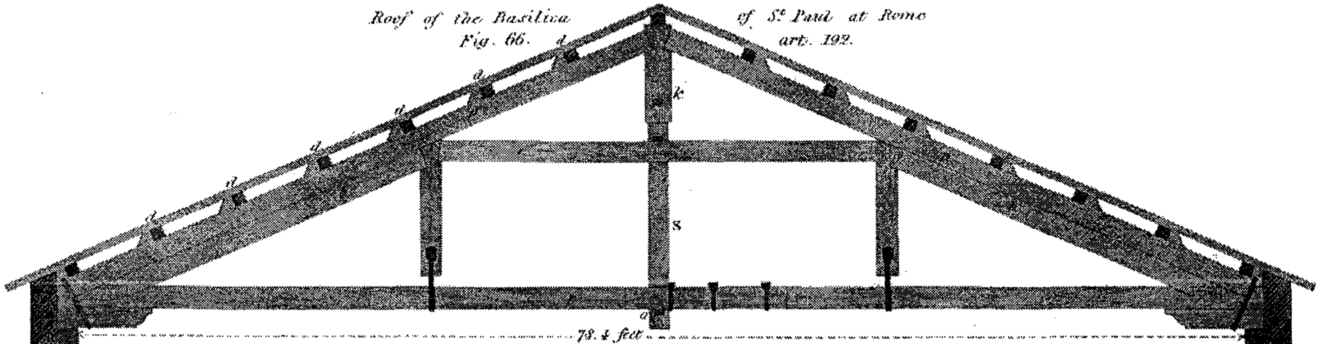



Fig. 67.

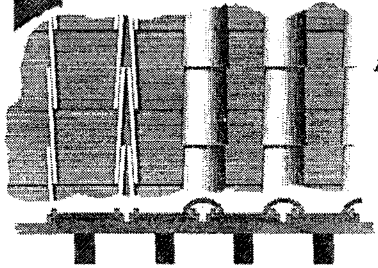
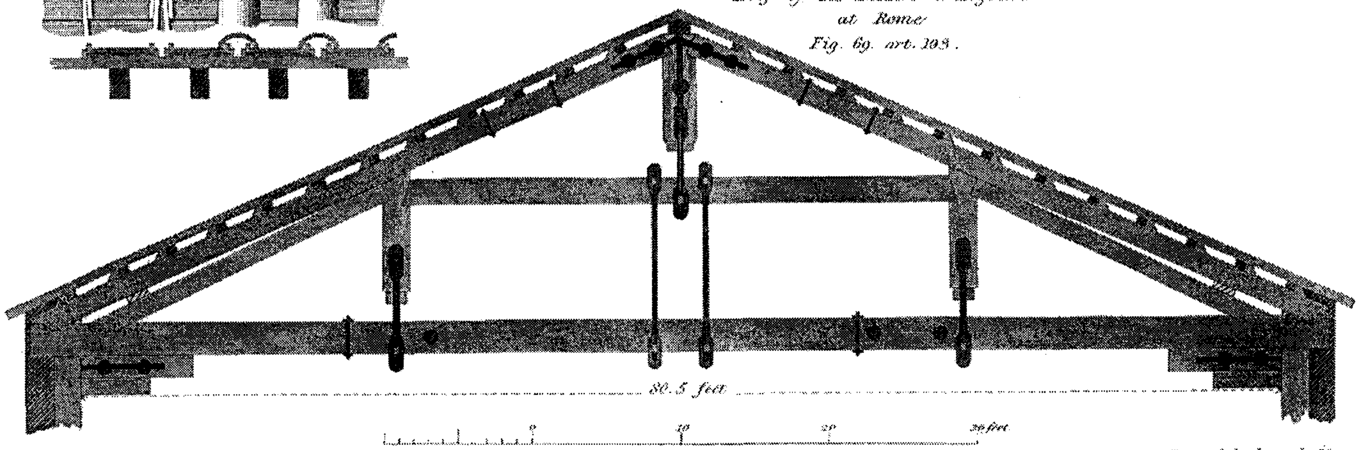


Fig. 68.
art 192

Roof of the Theatre d' Argentina at Rome
Fig. 69. art. 193.

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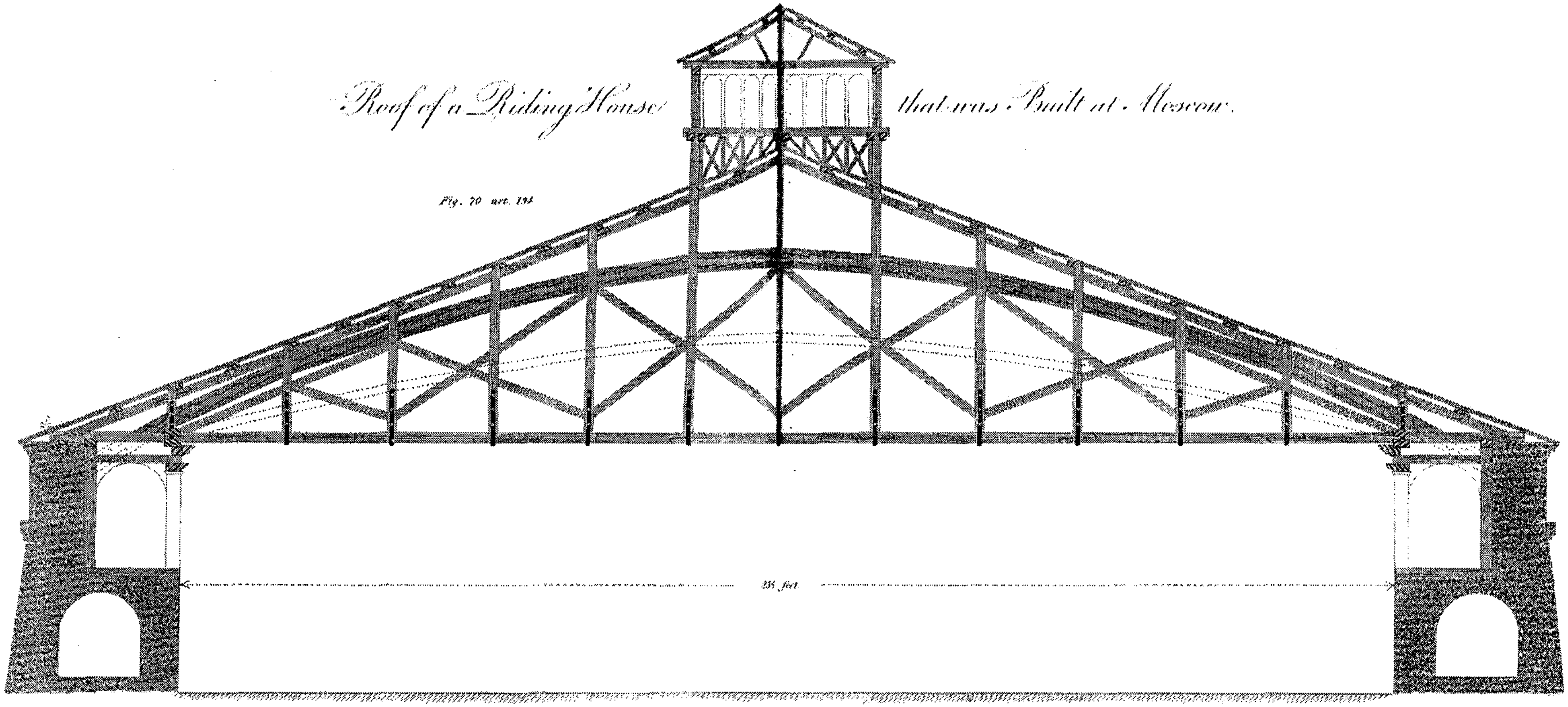
Roof of a Riding House that was Built at Moscow.

Fig. 70 art. 194

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# Domes.

PLATE XII.

Fig. 71. art. 197.

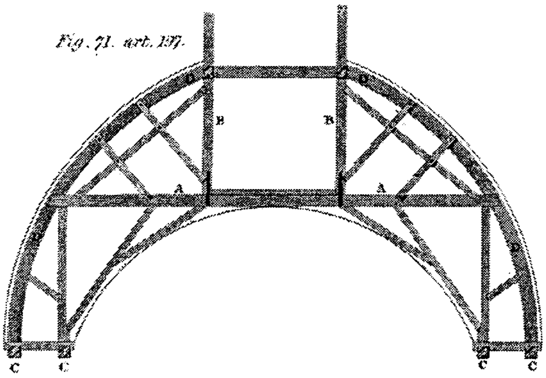



Fig. 74. art. 198.

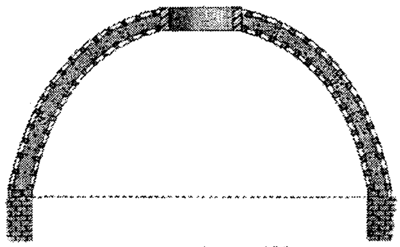


Fig. 75. art. 198.

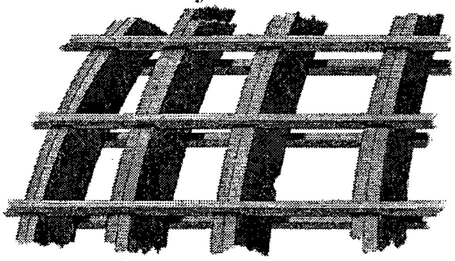


Fig. 72.

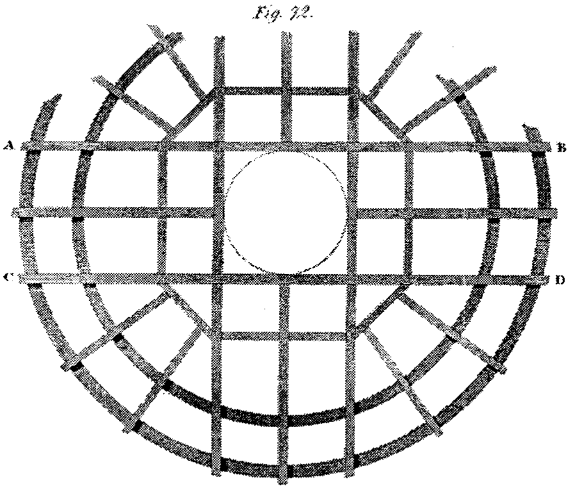



Fig. 76. art. 199.

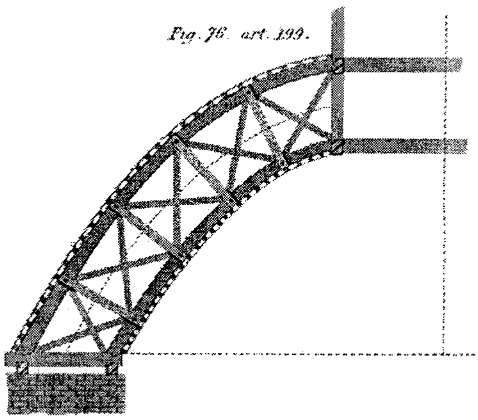


Fig. 73.

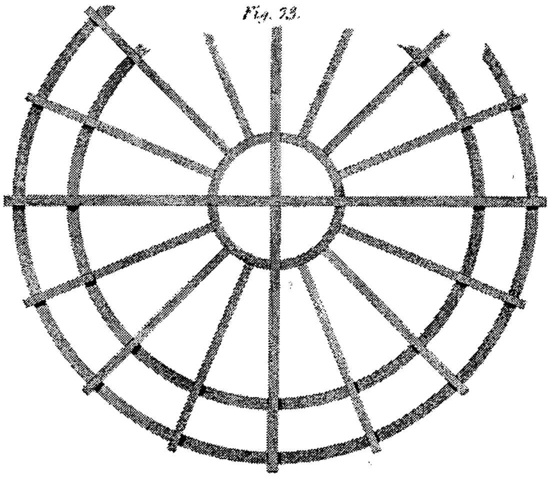
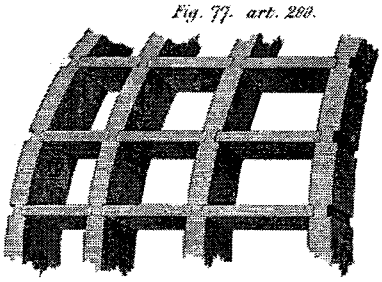


Fig. 77. art. 200.



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# Partitions and Centres.

PLATE XIII.

Fig. 78. art. 205.

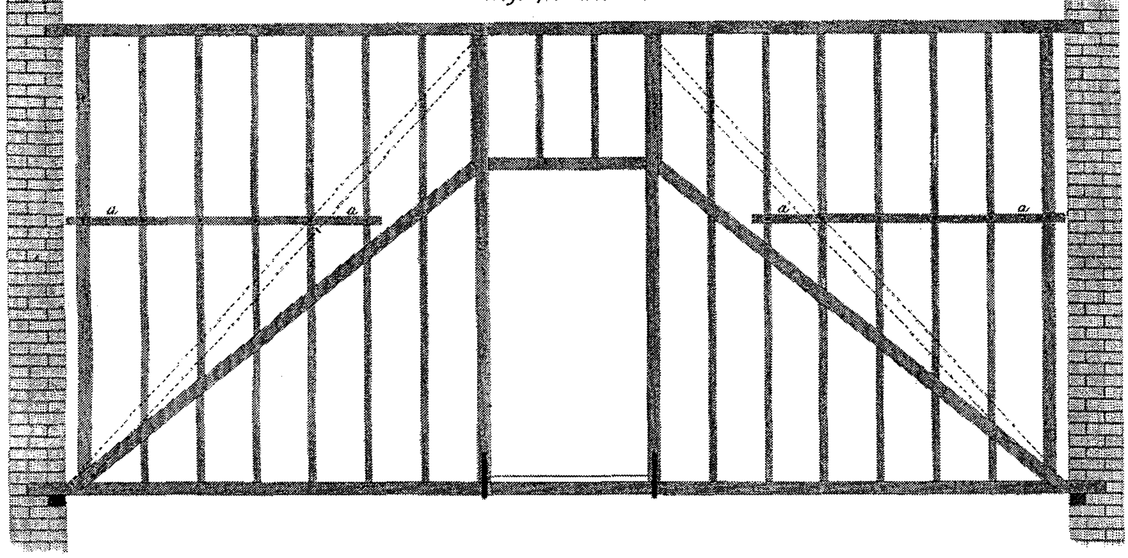
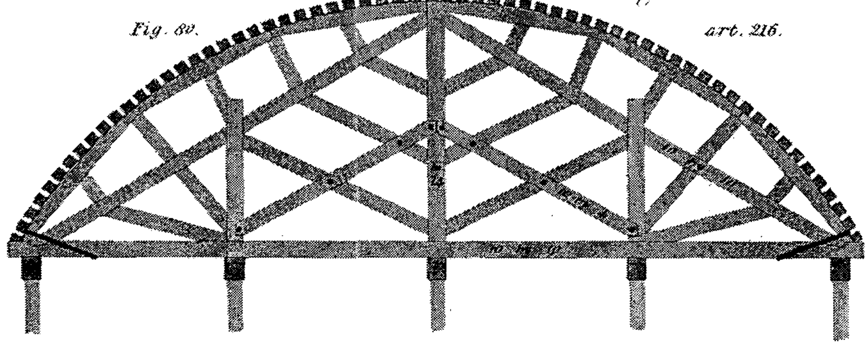



Fig. 79. art. 206.


## Centre of Coldstream Bridge.

Fig. 80. art. 216.



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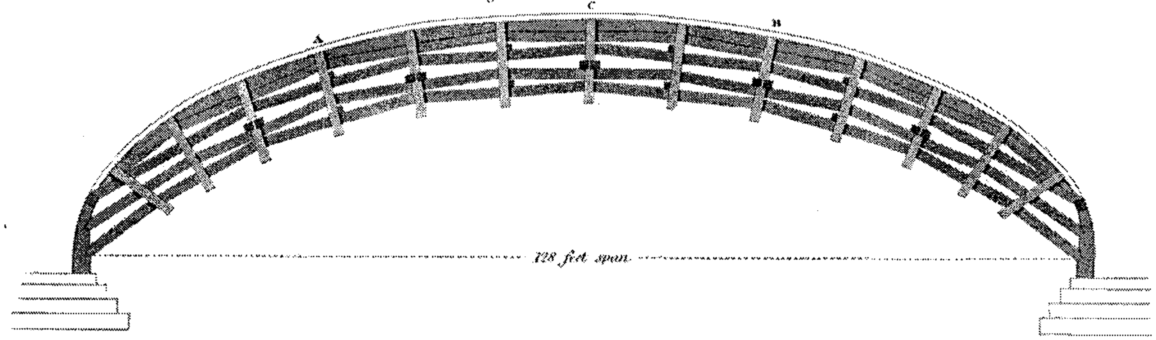
# Centres for Stone Bridges.

PLATE XIV.

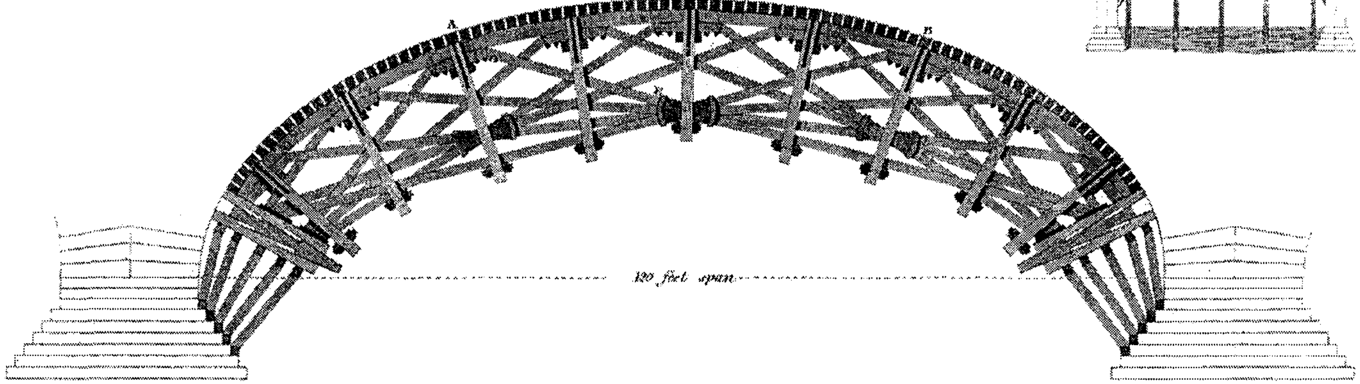
## The Centre used for the Bridge at Neuilly.

Fig. 82. Art. 217.



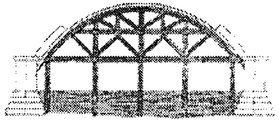

## The Centre used for the Waterloo Bridge.

Fig. 83. Art. 218.




## Centre of Conon Bridge.

Fig. 81. Art. 216.



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# Centres for Stone Bridges.

PLATE XV.

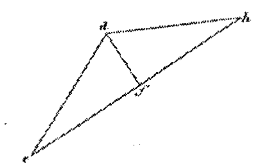



Fig. 84. Art. 219 and 223.

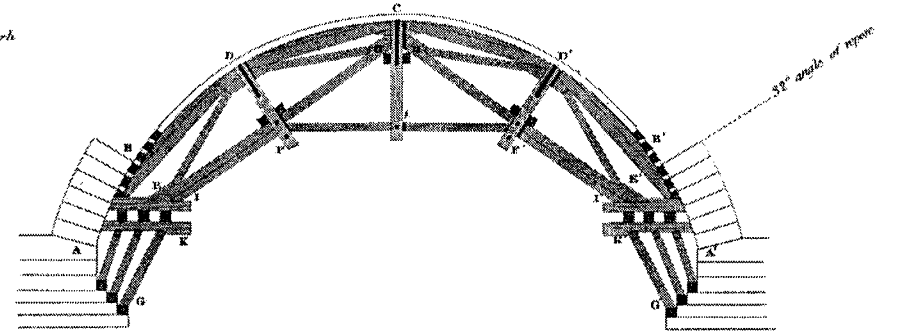
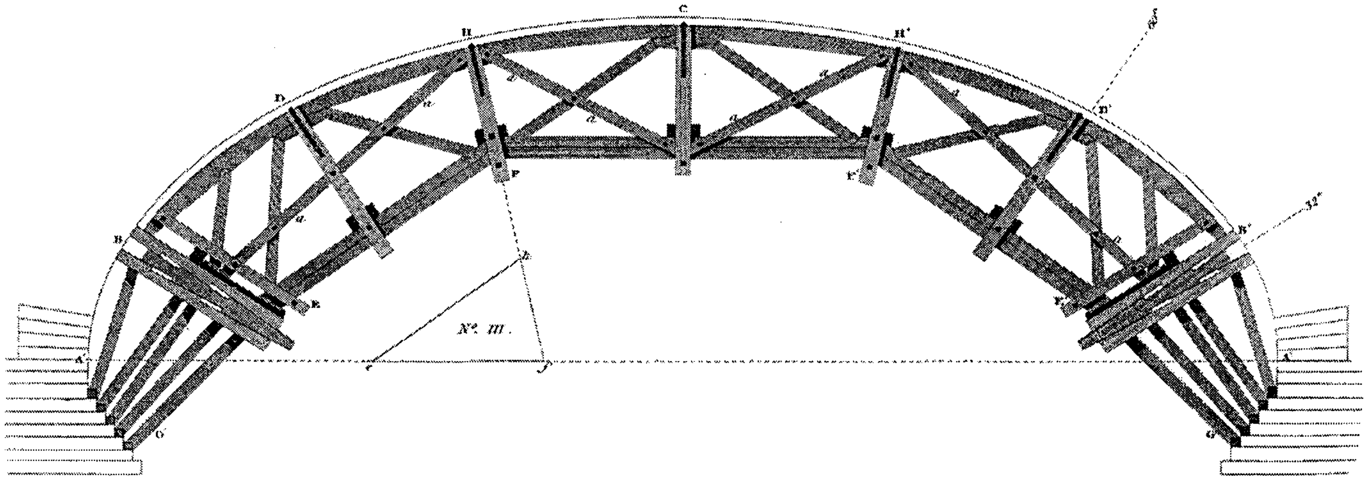



Fig. 85. Art. 220 and 224.

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# *Bridges.*

PLATE XVI.

*Fig. 86. Art 231.*

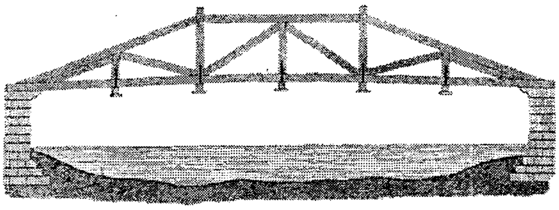


*Fig. 87. Art 231.*

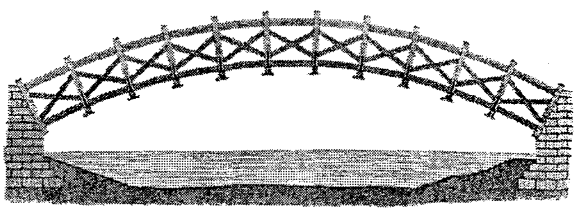


*Fig. 88. Bridge over the Brenta. Art. 266.*

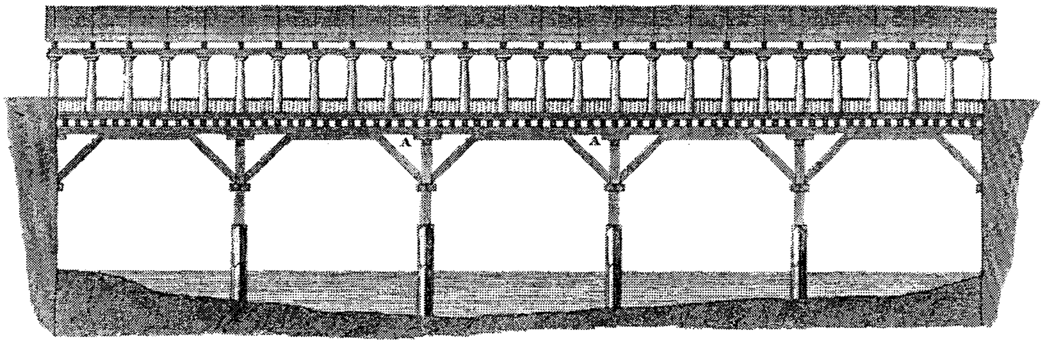


*Fig. 89. American Bridge. Art. 233.*

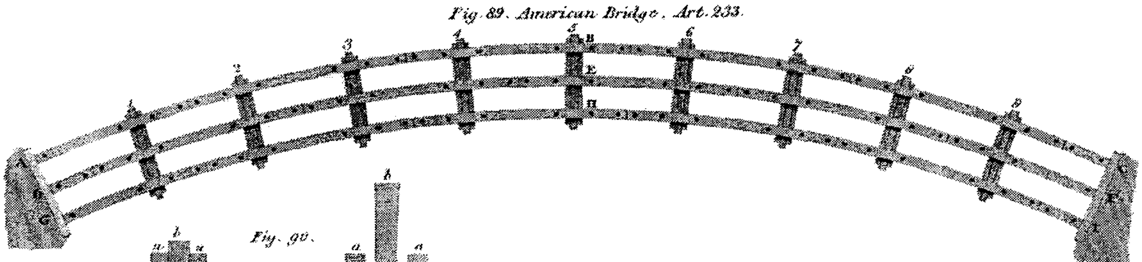


*Fig. 90.*

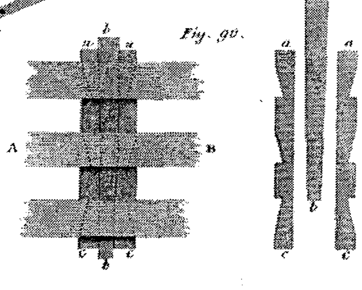


*Fig. 91.*

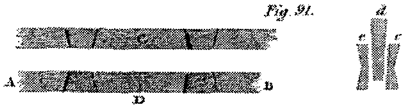


*Fig 92.*

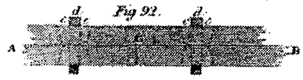
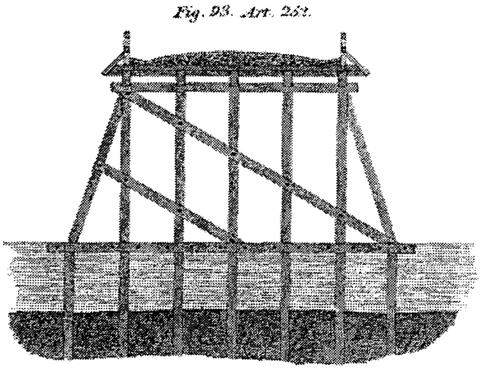


*Fig. 93. Art. 252.*



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*Engraved by James Lowry.*

# Bridges



Fig. 94 Freysingen Bridge, over the Isar, Art. 235.

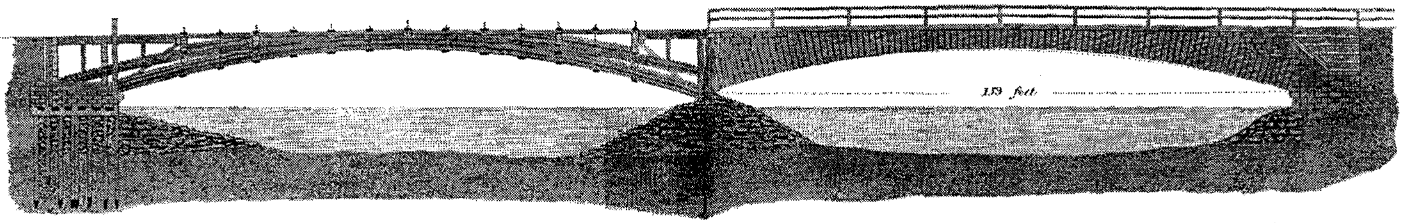



Fig. 96. Bridge of Bamberg, Art. 236.

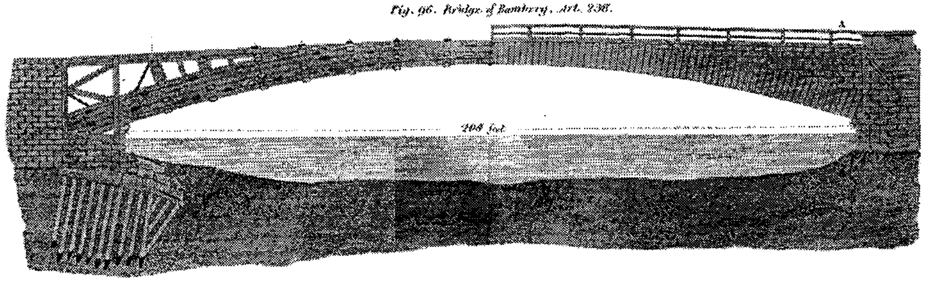



Fig. 98. Art. 256.

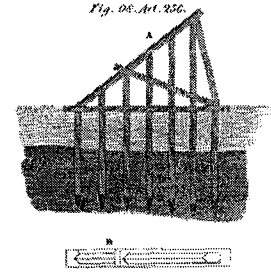



Fig. 95

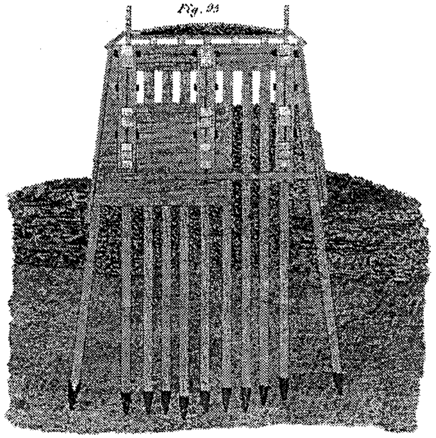


Fig. 97.

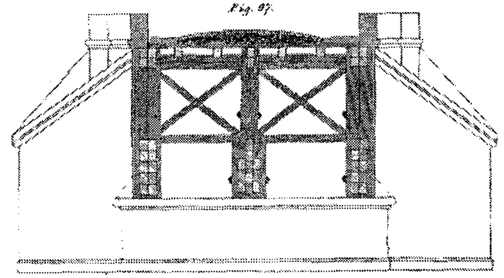
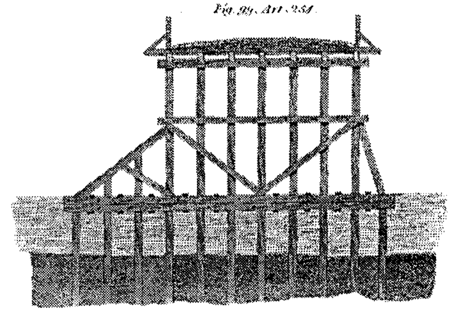


Fig. 99. Art. 254.



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Engraved by James Davis

# Construction of Bridges.

PLATE XVIII.

*Fig. 100. art. 258.*

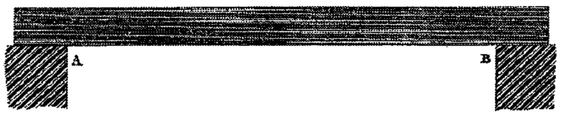



*Fig. 101.*

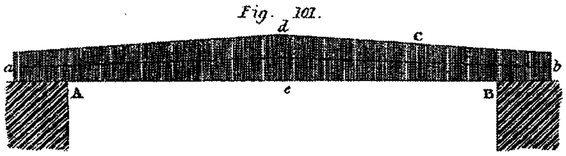



*Fig. 102.* *art. 259.*

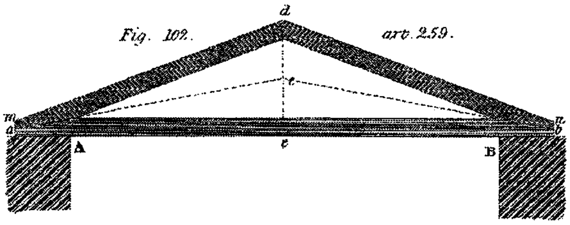



*Fig. 103. art. 260.*

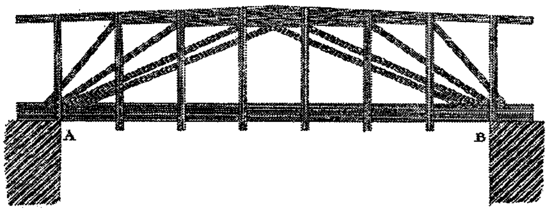



*Fig. 104. art. 261.*

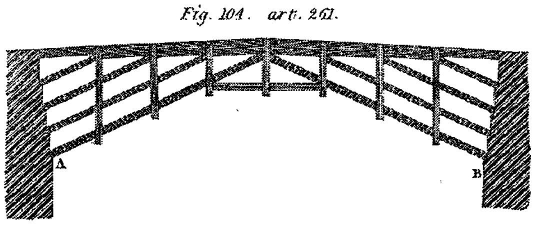



*Fig. 105. art. 262.*

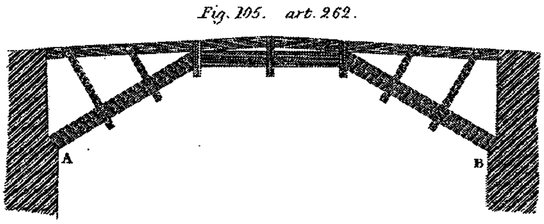



*Fig. 106. art. 263.*

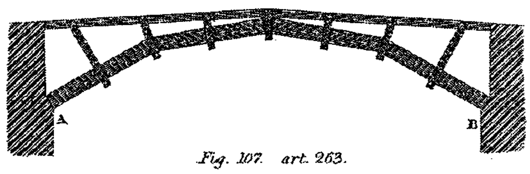



*Fig. 107. art. 263.*

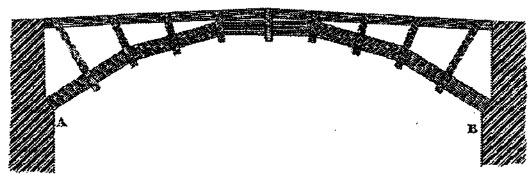



*Fig. 108. art. 264.*

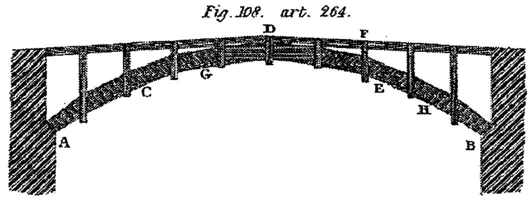



*Fig. 109. art. 264.*

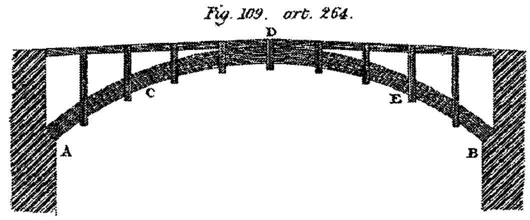



*Fig. 110. art. 265.*

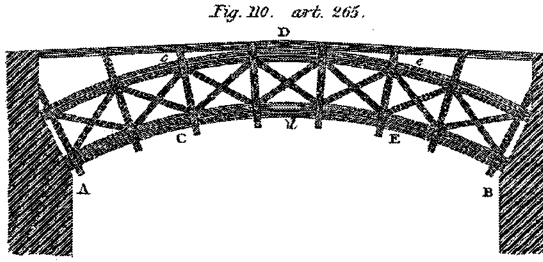
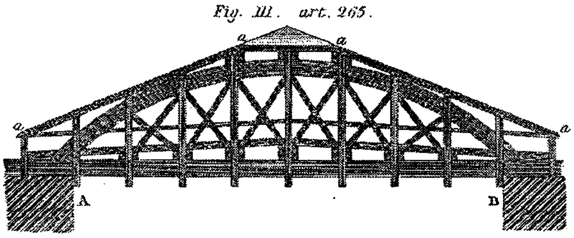



*Fig. 111. art. 265.*

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*Engraved by James Davis.*

*London, Published by J. Taylor, High Holborn, June 1. 1820.*

# Bridges.

PLATE XIX.

Fig. 113.

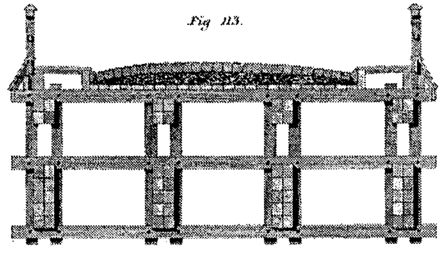


Fig. 112. Art. 268.

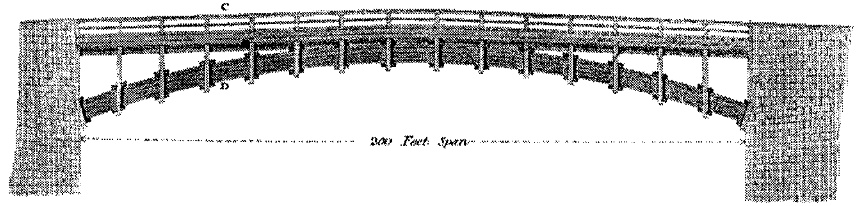



Fig. 114. Art. 269.

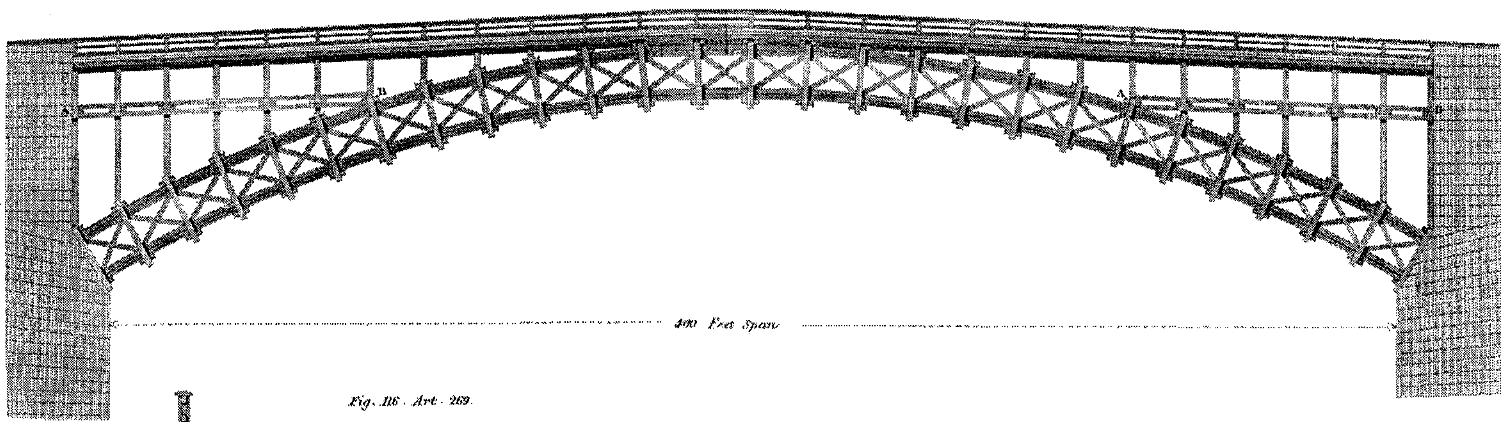



Fig. 116. Art. 269.

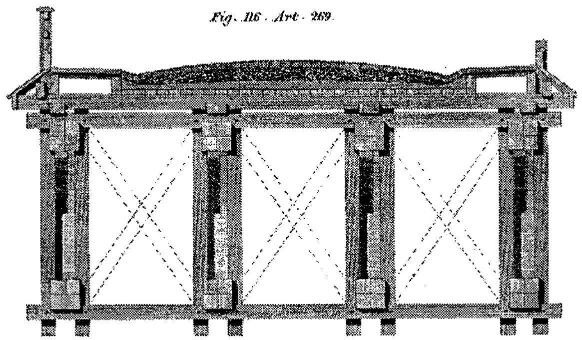
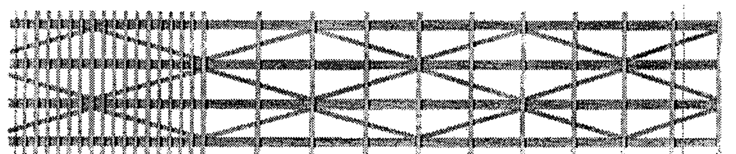


Fig. 115. Art. 269.



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# Bridges and Joints.

PLATE XX.

Fig. 117. Art. 253.

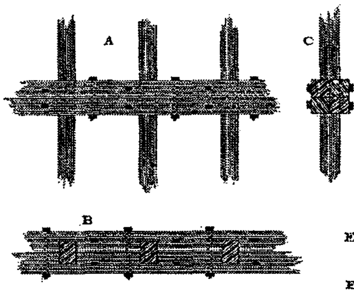


Fig. 118. Art. 254.

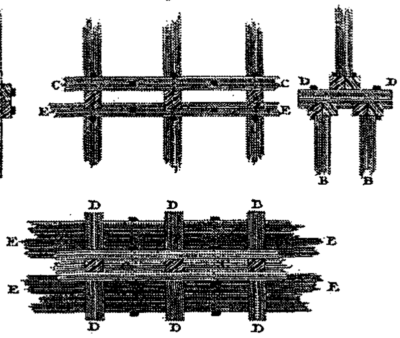


Fig. 119.
Art. 256.

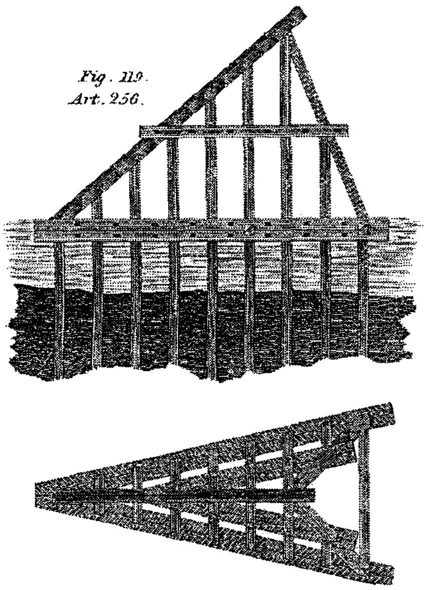

Fig. 120. Art. 280.

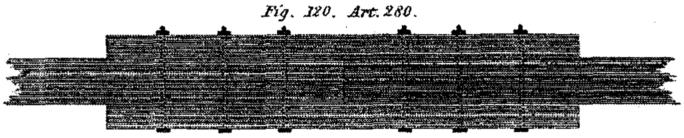

Fig. 121. Art. 280.

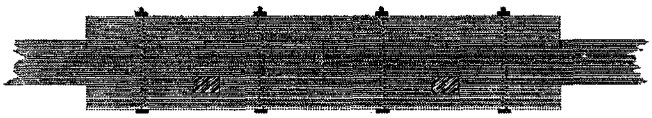

Fig. 122. Art. 281.

Fig. 123. Art. 282.

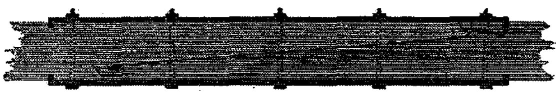

Fig. 124. Art. 283.

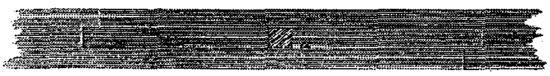

Fig. 125. Art. 284.

Fig. 126. Art. 285.

Fig. 127. Art. 285.

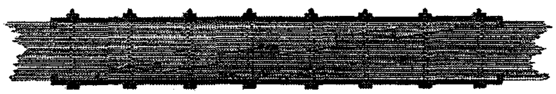

Fig. 128. Art. 285.

Fig. 129. Art. 286.

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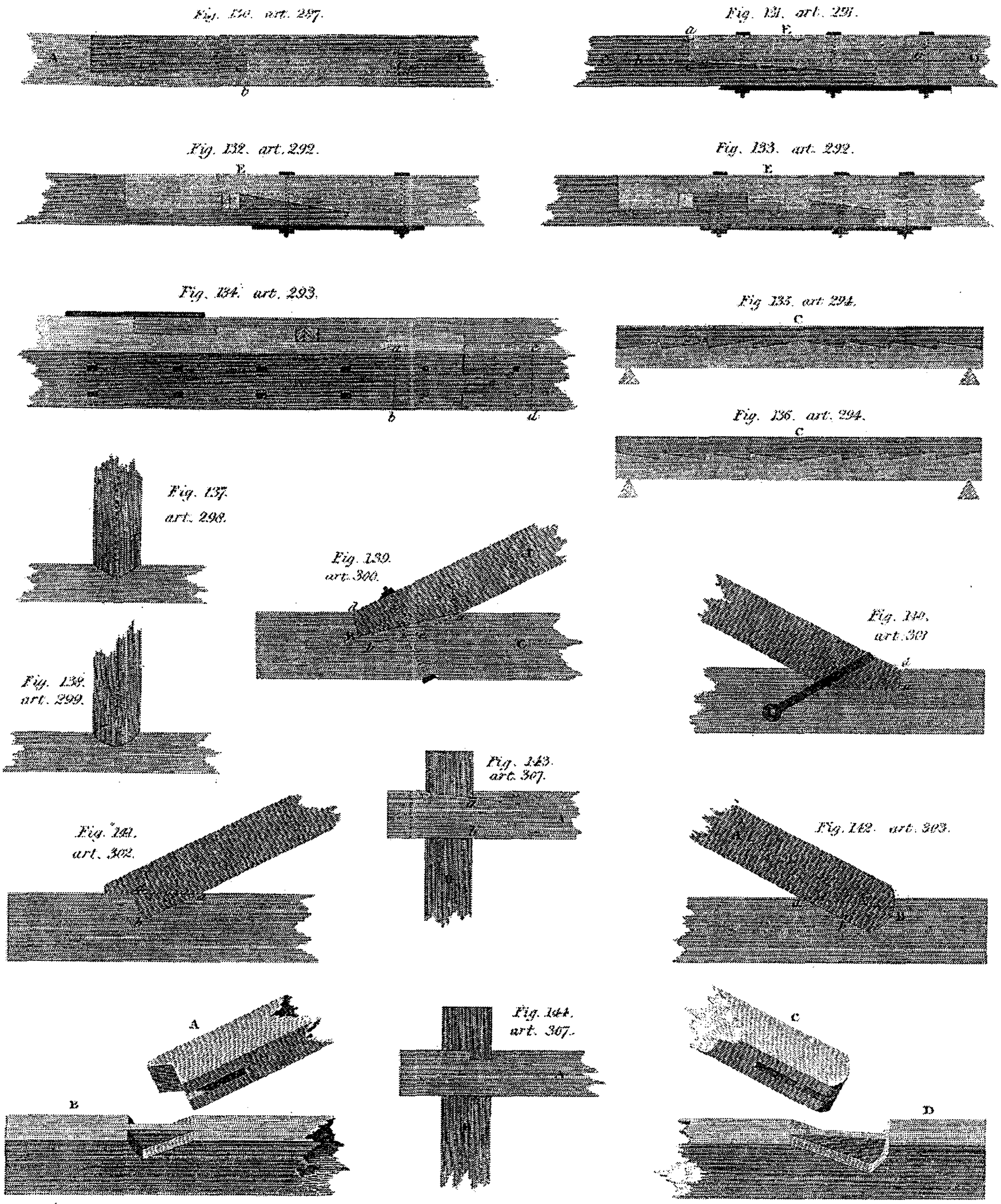
# Joints.



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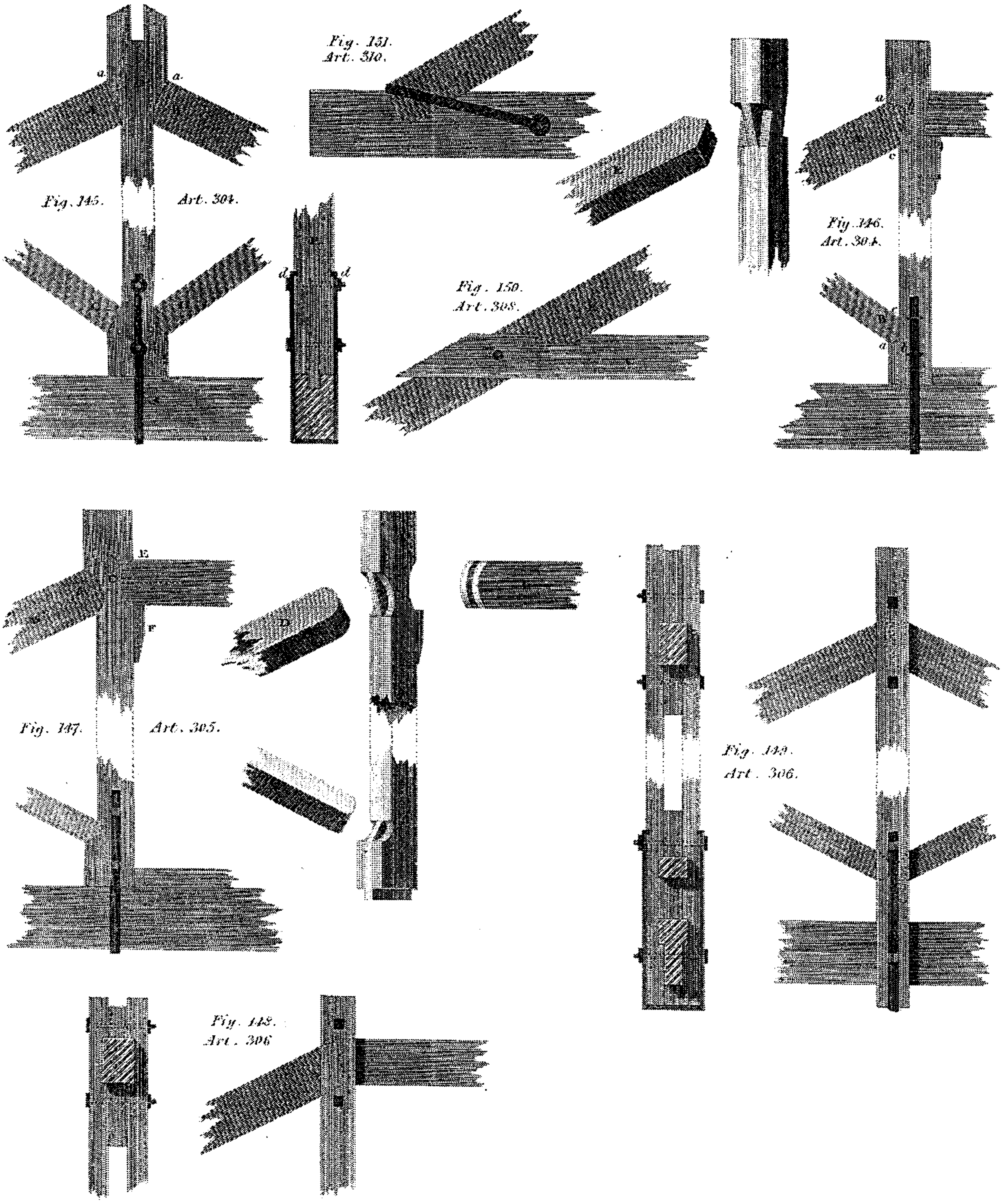
# Joints and Straps.

PLATE XXII.

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